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FASTRAN-II - A FATIGUE CRACK GROWTH STRUCTURAL ANALYSIS PROGRAM

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FASTRAN-II

A Fatigue Crack Growth Structural Analysis Program

I. SUMMARY

FASTRAN-II is a life-prediction code based on the crack-closure concept and is used to predict crack length against cycles from a specified initial crack size to failure for many common crack configurations found in structural components. FASTRAN-II is an update of the previous version FASTRAN. The life-prediction method used in FASTRAN-II is built around an analytical crack-closure model. The model is based on plasticity-induced fatigue-crack closure and is used to calculate the stress level at which the crack tip becomes fully open during cyclic loading. The applied cyclic loads may be constant-amplitude, variable-amplitude or spectrum loading. Several standardized flight-load spectra (TWIST, Mini-TWIST, FALSTAFF, and Felix-28) and other load spectra (Space Shuttle and Gaussian) are included as options. Spectrum loads may also be input by the user as either a list of stress points or a flight-by-flight sequence. The program uses the crack-closure concept to account for load-interaction effects. Tensile or compressive loads can be applied. The program contains seventeen predefined crack configurations; and the user can define one crack configuration. The crack-opening stresses, as a function of load history and crack length, are calculated from the model and the effective stress-intensity factor range, used to correlate fatigue-crack growth rates, may be either elastic or modified for plastic yielding at the crack tip. Ten example problems are included with the user guide to demonstrate the many options in FASTRAN-II.

A computer program DKEFF was also developed to analyze laboratory specimen data to obtain the effective stress-intensity factor against crack-growth rate relations used by FASTRAN-II. A user guide for this program is also included and discussed. (Computer programs are available from COSMIC.)

II. THEORETICAL MANUAL

A. Introduction

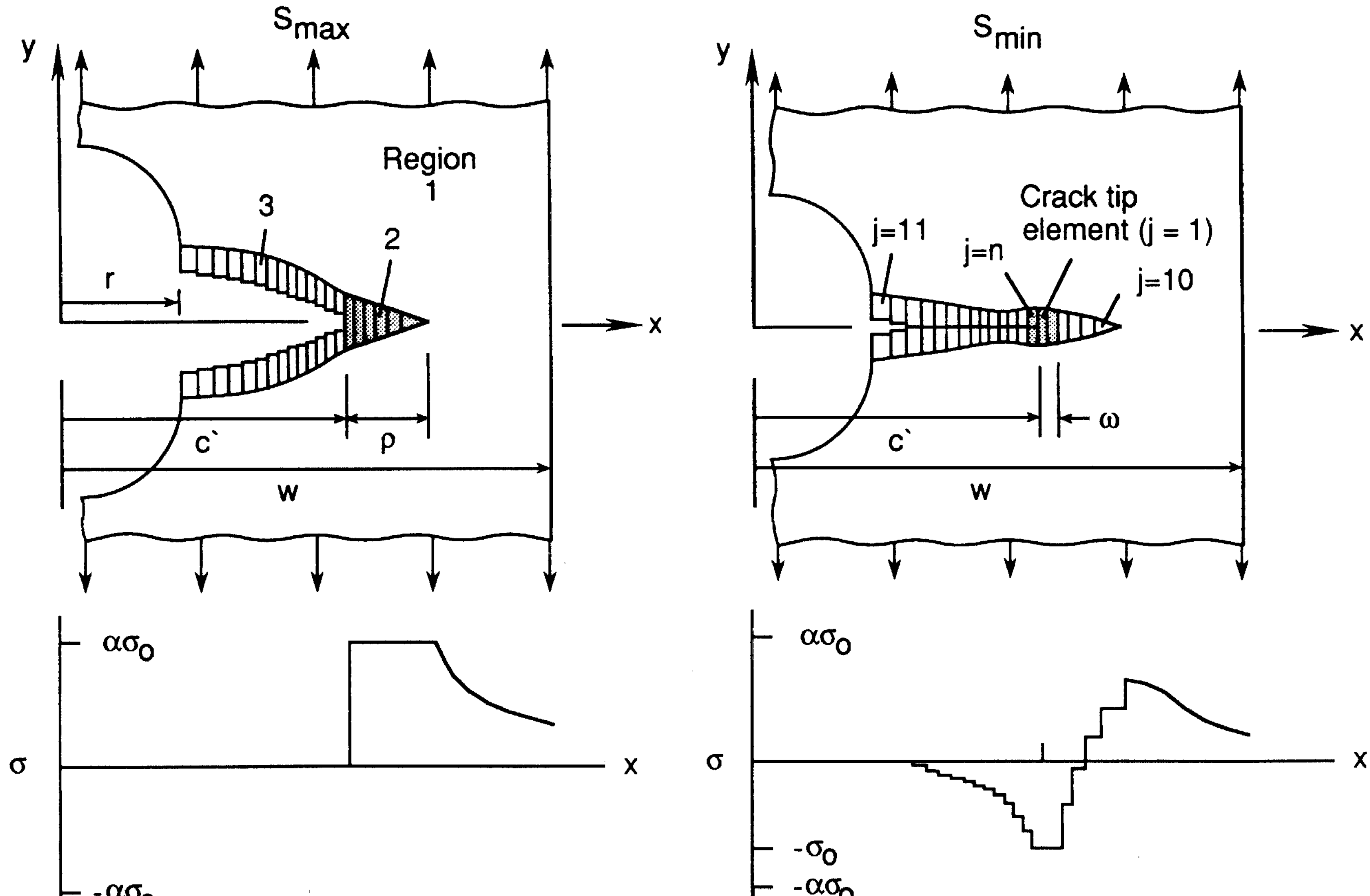
Fatigue tests on metallic materials have shown that fatigue cracks remain closed during part of the load cycle under constant- and variable-amplitude loading [1]. The crack-closure concept has been used to correlate crack growth rates under constant-amplitude loading and has been shown to be a significant factor in causing load-interaction effects on crack growth rates under variable-amplitude loading. Crack closure is caused by residual plastic deformation remaining in the wake of an advancing crack. To develop the rationale for predicting crack growth under general cyclic loading, a mathematical model of crack closure was developed [2] and verified for constant-amplitude, variable-amplitude and aircraft spectrum loading [3]. This user guide for FASTRAN-II is an update of a previous user guide developed for FASTRAN and submitted to COSMIC [4].

FASTRAN-II is a life-prediction code based on the crack-closure concept [2,3]. The program calculates crack length against cycles from a user specified initial crack size to failure for many common crack configurations found in structural components. The life-prediction method uses an analytical crack-closure model based on plasticity-induced fatigue crack closure. The crack-closure model calculates the stress level at which the fatigue crack tip becomes fully open during cyclic loading. The applied cyclic loads may be constant-amplitude, variable-amplitude or spectrum loading. The program uses the crack-closure concept to account for load-interaction effects (acceleration and retardation). Either tensile or compressive loads can be applied to a variety of crack configurations. The current program has seventeen predefined crack configurations and the user may define one other crack configuration by programming the stress-intensity factor equation in a special subroutine. The crack-opening stresses as a function of load history and crack length are calculated using either contact stress-intensity factors [2,3] or crack-surface displacement equations [5]; and the effective stress-intensity factor range (ΔK_{eff}) may be either elastic or modified for plastic yielding at the crack tip. Many of the input and internal variables used in the program are defined in the comment section at the beginning of the main program.

B. Analytical Crack-Closure Model

The analytical crack-closure model was developed for a central crack in a finite-width specimen subjected to uniform applied stress [2]. The model was later extended to through cracks emanating from a circular hole in a finite-width specimen also subjected to uniform applied stress [5]. The model was based on the Dugdale model [6], but modified to leave plastically deformed material in the wake of the crack. The primary advantage in using this model is that the plastic-zone size and crack-surface displacements are obtained by superposition of two elastic problems--a crack in a plate subjected to a remote uniform stress and a crack in a plate subjected to a uniform stress acting over a segment of the crack surface.

Figure 1 shows a schematic of the model at maximum and minimum applied stress. The model is composed of three regions: (1) a linear-elastic region containing a circular hole with a fictitious crack of half-length $c' + \rho$, (2) a plastic region of length ρ, and (3) a residual plastic deformation region along the crack surface. The physical crack is of length $c' - r$, where r is the radius of the hole. The length of the compressive plastic zone is ω. Region 1 is treated as an elastic continuum. Regions 2 and 3 are composed of rigid-perfectly plastic (constant stress) bar elements with a flow stress, σ_0. The flow stress (σ_0) is the average between the yield stress and the ultimate strength of the material. This is a first-order approximation for strain hardening. The shaded regions in Figure 1 indicate material that is in a plastic state. At any applied stress level, the bar elements are either intact (in the plastic zone) or broken (residual plastic deformation). The broken elements can carry compressive loads only, and then only if they are in contact. At the maximum applied stress and when the crack is fully open, the effects of state of stress on plastic-zone size and displacements are approximately accounted for by using a constraint factor, α. The constraint factor is used to elevate the tensile flow stress for the intact elements in the plastic zone. The effective flow stress $\alpha\sigma_0$ under simulated plane-stress conditions is σ_0 (usual Dugdale model) and under simulated plane-strain conditions is $3\sigma_0$. The value of $3\sigma_0$ was established from elastic-plastic finite-element analyses under plane-strain conditions using an elastic-perfectly-plastic material (normal stress elevation in the crack-tip region was about 2.7 from the analysis). For sheet and plate material, fully plane-strain conditions may not be possible. Irwin [7] suggested a modification to account for through-the-thickness variation in stress state by introducing a constraint factor of $\alpha = 1.73$ to represent nominal plane-strain conditions. At the minimum applied stress, some elements in the plastic zone and elements along the crack surface that are in contact may yield in compression when the contact or compressive stress reaches $-\sigma_0$. The loss of constraint under compression was justified on the grounds that when a crack closes the large stress gradient at the crack tip is greatly reduced and a more uniform stress field is produced.



(a) Maximum stress.

(b) Minimum stress.

Figure 1.- Schematic of analytical crack-closure model under cyclic loading.

C. Additions and Modifications in FASTRAN-II

FASTRAN-II has several additional options not available in the original version of FASTRAN. The new program has the ability to model different crack-growth properties in the crack depth (a) and crack length (c) directions, for surface or corner cracks, and the properties may be given in either equation or tabular form. To help the user input spectrum loadings not included as special options, two additional methods have been added: a list of stress points and a flight-by-flight input. Also, several additional flight-load spectra, Space Shuttle, Gaussian, Felix-28, Inverted FALSTAFF and clipped versions of TWIST and Mini-TWIST, were added to the preexisting standard load spectra TWIST, Mini-TWIST, and FALSTAFF in the original version. The ability to simulate proof testing on a center-crack tension specimen was added. In addition to applied stresses, crack growth can now be simulated under constant stress-intensity factor ranges for center-crack and compact-tension specimens. Several new predefined crack configurations were also added.

FASTRAN-II includes several modifications to the crack-closure model to improve crack-growth rate correlations and to calculate crack-opening stresses during variable-amplitude loading. These modifications will be briefly discussed here.

Closure-Model Activation.-FASTRAN-II, like FASTRAN, is a fatigue crack-growth program built around the analytical crack closure model. The closure model calculates the crack-opening stress as a function of applied stress history. During the crack-growth stage, the crack-opening stress is held constant for a certain amount of crack extension, Δc^* (see ref. 2). The stresses applied to the crack configuration are monitored during this stage for the highest stress (SMAXH), the lowest stress (SMINB) before SMAXH, and the lowest stress (SMINA) after SMAXH. Once the crack has grown the Δc^* increment, the closure model is activated and a new value of crack-opening stress is calculated using SMINB, SMAXH, SMINA and Δc^*. However, during the Δc^*-growth stage, several other events can activate the model. The model is automatically activated when the cycles needed to create Δc^* exceed 1000 (the original model used 300). Also, stress excursions are monitored, and if they exceed a preset value (such as large overloads or underloads), the model is activated. The process is repeated until the configuration fails or the desired crack length has been exceeded.

Crack-Length Calculations.-The calculation of Δc^* the crack-growth increment over which the crack-opening stress is held constant during constant-amplitude, variable-amplitude or spectrum loading was changed. In the original version, Δc^* was 5 percent of the monotonic plastic-zone size, ρ. In the revised version, Δc^* is set at 20 percent of an approximate cyclic plastic-zone size (ω) as

$$\Delta c^* = 0.2\ \omega = 0.2\ (\rho/4)\ (1 - R_x)^2 \tag{1}$$

where ρ is the plastic-zone size using the current maximum stress and R_x is the stress ratio using the current minimum and maximum applied stress. For stress ratios less than zero, R_x is set equal to zero. Note that for a stress ratio of zero, equation (1) reduces to 5 percent of the plastic-zone size as used in the original version. This modification was made to improve the crack-opening stress calculations under high stress ratio conditions.

Crack-Opening Stresses.-The method used to calculate crack-opening stresses (S_o) in the original version of FASTRAN assumed that the crack-growth increments were small compared to crack length [2]. In proof testing or severe spectrum loading, however, crack-growth increments may be large compared to crack length. Therefore, the closure-model analysis in FASTRAN-II was modified. The contact stress-intensity factor equation for calculating crack-opening stress (eq. (27) in ref. 2) was changed to

$$S_o' = S_{min} - \sum_{j=11}^{n} (2\sigma_j/\pi)\ [\arcsin B_2 - \arcsin B_1]_j \tag{2}$$

where $$B_k = [\sin(\pi b_k/2w)]/[\sin(\pi c/2w)] \quad \text{for } k = 1 \text{ or } 2. \tag{3}$$

The prime denotes the modified crack-opening stress. The index j refers to elements along the crack surface that are used to model plastic and residual-plastic deformations, as shown in Figure 1(b). The crack length, c, is the sum of the hole radius plus all of the elements from j = 11 to n. The dimension b_k denotes an edge of an element. The width of an element is $b_2 - b_1$. The specimen width (w) is measured from the centerline or edge. The modification changed the upper limit of the summation in equation (2) from n-1 to n to reflect the change in formulation from the crack length before growth to actual or current crack length. Element 1 is the first intact element at the crack tip. Elements 1 to 10 are always ahead of the current crack tip and model the plastic zone, ρ. The intact elements in the plastic zone may carry tensile stresses up to $\alpha\sigma_o$ and compressive stresses down to $-\sigma_0$. Elements 11 to n are located along the crack surface between the initial notch and the current crack tip. In the physical model, the crack was extended by the width of the n^{th} element at the maximum applied stress, see reference 2. The physical crack extension was Δc^*. However, in the computation of the crack-opening stress in equation (2), the total width of the n^{th} element (Δc^*) was not used. The width used in equation (2) for element n was the largest crack growth increment during the generation of Δc^*. For low fatigue crack growth rates, the width of element n was generally very small compared to Δc^*. But for proof testing, the width of element n was equal to Δc^*, the crack extension during proof loading. At the minimum applied stress, elements along the crack surface that are in contact carry σ_j, the element contact stress, otherwise the element stress is zero. For low fatigue crack growth rates, S_0' calculated from equation (2) was nearly equal to S_0 calculated from the previous equation developed in reference 2. However, for large crack-growth increments, S_0' from equation (2) is now a function of crack extension. See reference 8 for further details on this modification and on the proof-test application.

Crack-Opening Stress Equations.-In reference 9, crack-opening stress equations for constant-amplitude loading were developed from the analytical crack-closure model (S_0) calculations. These equations were fit to the results from the closure model and gave S_0 as a function of stress ratio (R), maximum stress level (S_{max}/σ_0) and a constraint factor (α). Herein, a modification to correct these equations for large crack-growth extensions or rates is presented [8]. In the closure model analysis, the n^{th} element always carry the compressive flow stress ($-\sigma_0$) during unloading. Thus, the contribution of this element to the crack-opening stress can be estimated as follows. An approximate equation for S_0' under constant-amplitude loading was derived from stress-intensity factors for a crack in an infinite plate assuming that the contact stress distribution was linear. The assumed contact stress distribution along the crack surfaces varied from the compressive flow stress ($-\sigma_0$) at the crack tip and to zero at the end of the contact region. The modification to correct the crack-opening stress equation is given by

$$S_0' = S_0 + 0.3\ \sigma_0\ \sqrt{\Delta c/c}\ /F \qquad \text{for } S_{max}/\sigma_0 < 0.6 \tag{4}$$

where Δc is the crack-growth increment (or rate per one cycle) and c is the current crack length. The boundary-correction factor, F, was added to these equations to account for the influence of finite width. The crack-opening stress S_0 is calculated from equations developed in reference 9. These equations will be presented later. Comparisons with the model showed that equation (4) was reasonably accurate for a wide range in constant-amplitude loading conditions for S_{max}/σ_0 less than about 0.6. The difference between S_0' and S_0 was only significant (greater than a 2 percent effect on crack-opening stresses) for growth rates greater than about 10^{-5} m/cycle. For $S_{max}/\sigma_0 > 0.6$, the crack-opening stresses should be obtained from FASTRAN-II by conducting an analysis of the test specimen.

The crack-opening stress equation developed in reference 9 will be presented here for completeness. These equations were developed by fitting to the calculated results from the closure model for a center-crack tension specimen. Note that the crack-opening stress S_0 was calculated from equation (2) where n is replaced by n-1 (original formulation). The equation was given by

$$S_0/S_{max} = A_0 + A_1 R + A_2 R^2 + A_3 R^3 \qquad \text{for } R \geq 0 \tag{5}$$

and

$$S_0/S_{max} = A_0 + A_1 R \qquad \text{for } R < 0 \tag{6}$$

where $R = S_{min}/S_{max}$, $S_{max} < 0.8\sigma_0$, $S_{min} > -\sigma_0$, $S_0 = S_{min}$ if S_0/S_{max} is less than R, and $S_0/S_{max} = 0$ if S_0/S_{max} is negative. The A_i coefficients are functions of α and S_{max}/σ_0 and are given by:

$$\left.\begin{aligned} A_0 &= (0.825 - 0.34\alpha + 0.05\alpha^2)\ [\cos(\pi S_{max} F/2\sigma_0)]^{1/\alpha} \\ A_1 &= (0.415 - 0.071\alpha)\ S_{max} F/\sigma_0 \\ A_2 &= 1 - A_0 - A_1 - A_3 \\ A_3 &= 2A_0 + A_1 - 1 \end{aligned}\right\} \tag{7}$$

for α = 1 to 3. Again, the boundary-correction factor, F, was added to these equations to account for the influence of finite width on crack-opening stresses. See reference 8 for a comparison between these equations and the model calculations for a wide range in stress levels and stress ratios. Equations (4)-(7) give approximate crack-opening stress equations that agree fairly well with the results from the modified analytical crack closure model. These equations are used to correlate fatigue crack-growth rate data to obtain ΔK_{eff} against crack-growth rate relations. (These equations are programed in Subroutine SOEQN.)

Crack-Opening Stresses for the Compact Specimen.-Equations (5) and (6) were originally developed for a through crack in a center-crack tension specimen subjected to remote stress. Similar equations are not available for the compact specimen. Because the compact specimen is used quite often to obtain crack-growth rate data, crack-opening expressions are needed to develop baseline ΔK_{eff}-rate relations. A simple approximation can be made to estimate crack-opening stresses. The approximation is based on matching stress-intensity factors from the compact specimen to that for a center-crack tension specimen. A stress S'_{max} is applied to a center-crack specimen having the same crack length and width as the configuration of interest so that the same stress-intensity factor is developed. Thus, the plastic-zone size, the local crack surface displacements, the local residual plastic deformations and the crack-opening stresses would be nearly the same in both configurations. For example, the stress-intensity factor for the compact-tension specimen is

$$K_{ct} = P/(wt)\ \sqrt{\pi c}\ \ F_{ct} \tag{8}$$

where P is the applied load and F_{ct} is the boundary-correction factor. Note that equation (8) is expressed as a stress P/(wt) times the square-root of the crack length instead of in the usual form, $P/(t\sqrt{w})$. The stress-intensity factor for the center-crack tension specimen is

$$K_{cct} = S'_{max}\ \sqrt{\pi c}\ \ F_{cct} \tag{9}$$

where F_{cct} is the boundary-correction factor. Equating equations (8) and (9) gives

$$S'_{max} = P/(wt)\ F_{ct}/F_{cct} \tag{10}$$

Thus, S'_{max} replaces S_{max} in equation (5) to estimate the crack-opening stress for the compact-tension specimen ($R \geq 0$). This approach gives crack-opening stresses for the compact specimen that are a function of stress ratio, stress level, and constraint. All other crack configurations in FASTRAN-II are subjected to a remote applied stress and the original procedure is expected to give accurate crack-opening stresses. Further study is needed to evaluate the K-analogy procedure for other crack configurations, especially the three-dimensional crack configurations.

Effective Stress-Intensity Factor Range.-The effective stress-intensity factor range developed by Elber [1] was based on linear-elastic analyses. For high stress-intensity factors, such as those during proof testing or near failure, plastic-zone sizes are no longer small compared to crack size and linear-elastic analyses are inadequate. To modify the analysis to account for plasticity, a portion of the Dugdale plastic-zone length (ρ), like the well-known Irwin plastic-zone correction, was added to the current crack length (c). Thus, the effective stress-intensity factor range corrected for plasticity is

$$\Delta\bar{K}_{eff} = (S - S_0') \sqrt{\pi d} \;\; F(d/w, d/r, \ldots) \qquad (11)$$

where S is the maximum applied stress, S_0' is the crack-opening stress developed by the previous cyclic load history, $d = c_x + \omega/4$, where c_x is the current crack length (c) plus the crack-growth rate (dc/dN) per one cycle and ω is the closure-corrected cyclic plastic-zone size. For large crack-growth rates, the effective stress-intensity factor against rate relation is used as a resistance curve [8], like a K_R resistance curve, and the crack driving force is calculated at the current crack length plus any crack extension value. The boundary-correction factor F may be a function of width, thickness, hole or notch radius and other configuration parameters. The boundary-correction factor F is evaluated using the fictitious crack length, d. The plasticity correction of "one-quarter of the cyclic plastic zone" was developed in reference 10 by equating an estimate of the cyclic J-integral (ΔJ) to a plasticity-corrected cyclic stress-intensity factor (ΔK_p). (Note: The use of $\omega/4$ as the plasticity correction needs further experimental and analytical verification.) The closure-corrected cyclic plastic-zone size (ω) is approximated by

$$\omega = (\rho/4)\ (1 - R_{eff})^2 = (\rho/4)\ (1 - S_0'/S_{max})^2 \qquad (12)$$

where ρ is the Dugdale plastic-zone size and R_{eff} is the ratio of crack-opening stress to the maximum stress. The user has the option to select either elastic or plasticity-corrected stress-intensity factors. If elastic stress-intensity factors are selected, then d = c in equation (11). With either option, the baseline crack-growth rate data must be analyzed under the same conditions, that is, using either elastic or plasticity-corrected stress-intensity factors.

The plastic-zone length (ρ) for a center-crack tension specimen was determined from an infinite periodic array of Dugdale models and was modified (see ref. 5) for a finite-width specimen. The modified equation is

$$\rho = c\{(2w/\pi c) \arcsin [\sin(\pi c/2w) \sec(\pi Sf/2\alpha\sigma_0)] - 1\} \qquad (13)$$

where $f = 1 + 0.22(c/w)^2$, α is the constraint factor [2], and σ_0 is the flow stress (average between yield stress and ultimate tensile strength). The constraint factor elevates the flow stress at the crack tip due to the three-dimensional stress state. For plane-stress conditions, α is assumed to be unity and for plane strain, $\alpha = 3$. For other crack configurations, the plastic-zone size may be estimated by using the small-scale yielding solution

$$\rho = \pi/8\ (K_{max}/\alpha\sigma_0)^2 \qquad (14)$$

D. Effective Stress-Intensity Factor against Crack-Growth Rate

To make life predictions, ΔK_{eff} (or $\Delta\bar{K}_{eff}$) as a function of the crack-growth rate must be obtained for the material of interest. Fatigue crack-growth rate data should be obtained over the widest range in rates possible (from threshold to fracture), especially if spectrum load predictions are required. Data obtained on the crack configuration of interest would be helpful but is not essential. The use of the plasticity-corrected stress-intensity factor is only necessary if proof testing or severe loading (such as low cycle fatigue conditions) are of interest. Most damage-tolerant life calculations can be performed using the linear elastic stress-intensity factor analysis with crack-closure modifications.

To obtain the baseline ΔK_{eff} (or $\Delta\bar{K}_{eff}$) against crack-growth rate relations, the fatigue crack-growth rate data must be analyzed using the equations previously presented. A computer program DKEFF (dkeff.for) was also developed to help the user determine the effective stress-intensity factor range against crack-growth rate relations. A user guide for this program is given in Section VII.

Under constant-amplitude loading, the only unknown in the equations is the constraint factor, α. The constraint factor is determined by finding (by trial-and-error) an α value that will correlate the constant-amplitude fatigue-crack-growth-rate data over a wide range in stress ratios, as shown in references 3, 5, 8, 9, and 11. This correlation should produce a unique relationship between ΔK_{eff} (or $\Delta\bar{K}_{eff}$) and crack-growth rate, as shown in Figure 2. The ΔK-rate (linear-elastic fracture mechanics) data on 7075-T6 aluminum alloy, shown in Figure 2(a), were generated by C. M. Hudson [19] and E. P. Phillips (unpublished) at the NASA Langley Research Center. The values of α for the ΔK_{eff}-rate correlation, shown in Figure 2(b), were determined by trial-and-error. The variable-constraint (α) regime ($1.8 > \alpha > 1.2$) was associated with the transition region from flat- to slant-crack growth (see ref. 11).

In the large-crack-growth threshold regime for some materials, the plasticity-induced closure model may not be able to collapse the threshold (ΔK-rate) data onto a unique ΔK_{eff}-rate relation because of other forms of closure. Roughness- and oxide-induced closure (see for example, ref. 20) appear to be more relevant in the threshold regime than plasticity-induced closure. Further study, however, is needed to assess the interactions between plasticity-, roughness- and oxide-induced closure in this regime. If the plasticity-induced closure model is not able to give a unique ΔK_{eff} relation in the threshold regime, it is suggested that the high stress ratio ($R > 0.5$) data be used to establish the ΔK_{eff} relationship.

For variable-amplitude or spectrum load crack-growth predictions, the constraint factor (α) should also be verified by some simple tests, such as crack growth after a single-spike overload. Constraint factors appear to be more sensitive to crack-growth delays caused by single-spike overloads than to crack growth under constant-amplitude loading at different stress ratios. Higher values of constraint (α) will cause less load-interaction effects, such as retardation or acceleration, than lower values of constraint. Thus, spike-overload tests may be more useful in establishing values of α than constant-amplitude tests (see ref. 21).

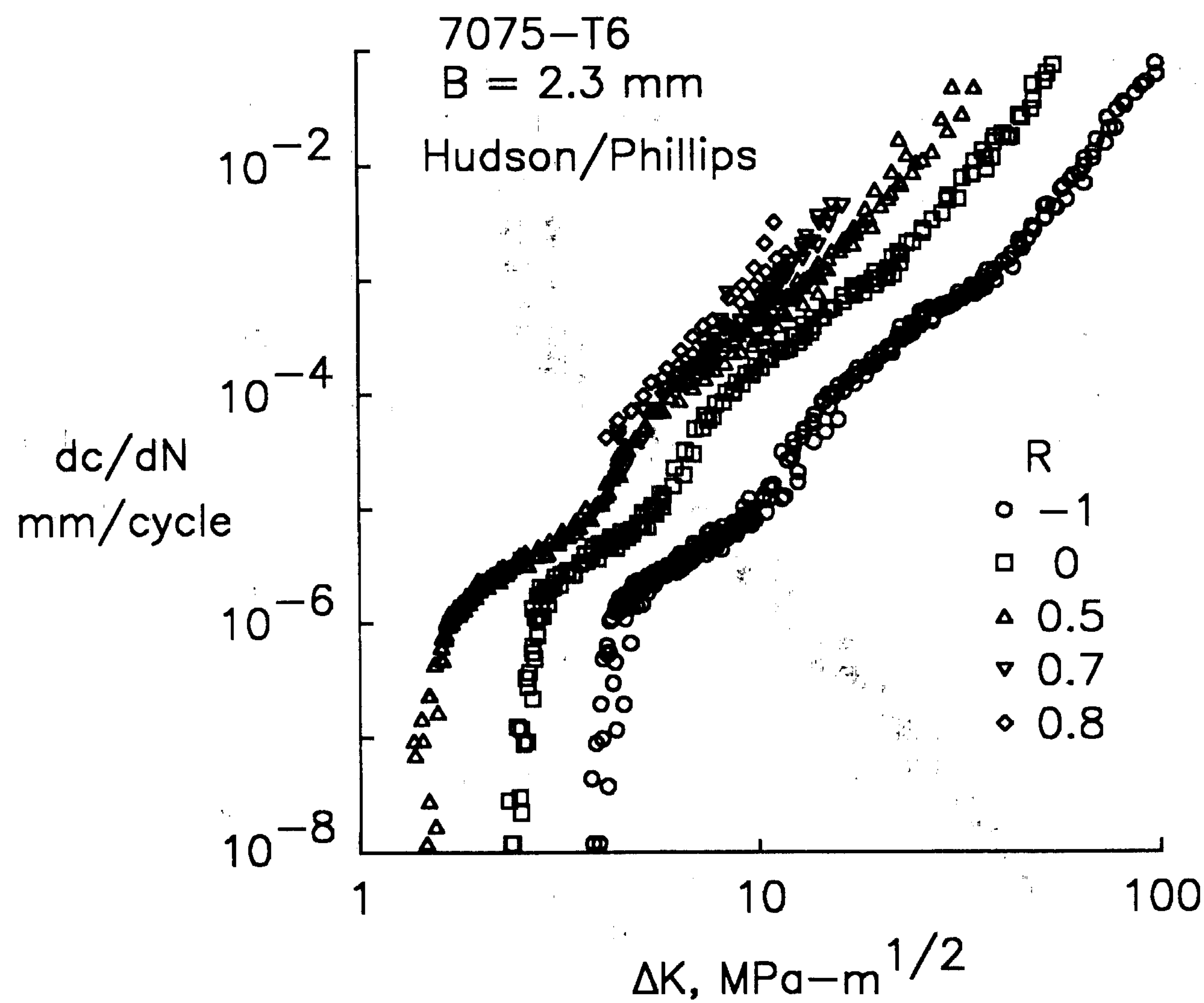


Figure 2(a).- Correlation of ΔK against rate for various stress ratios using linear-elastic fracture mechanics.

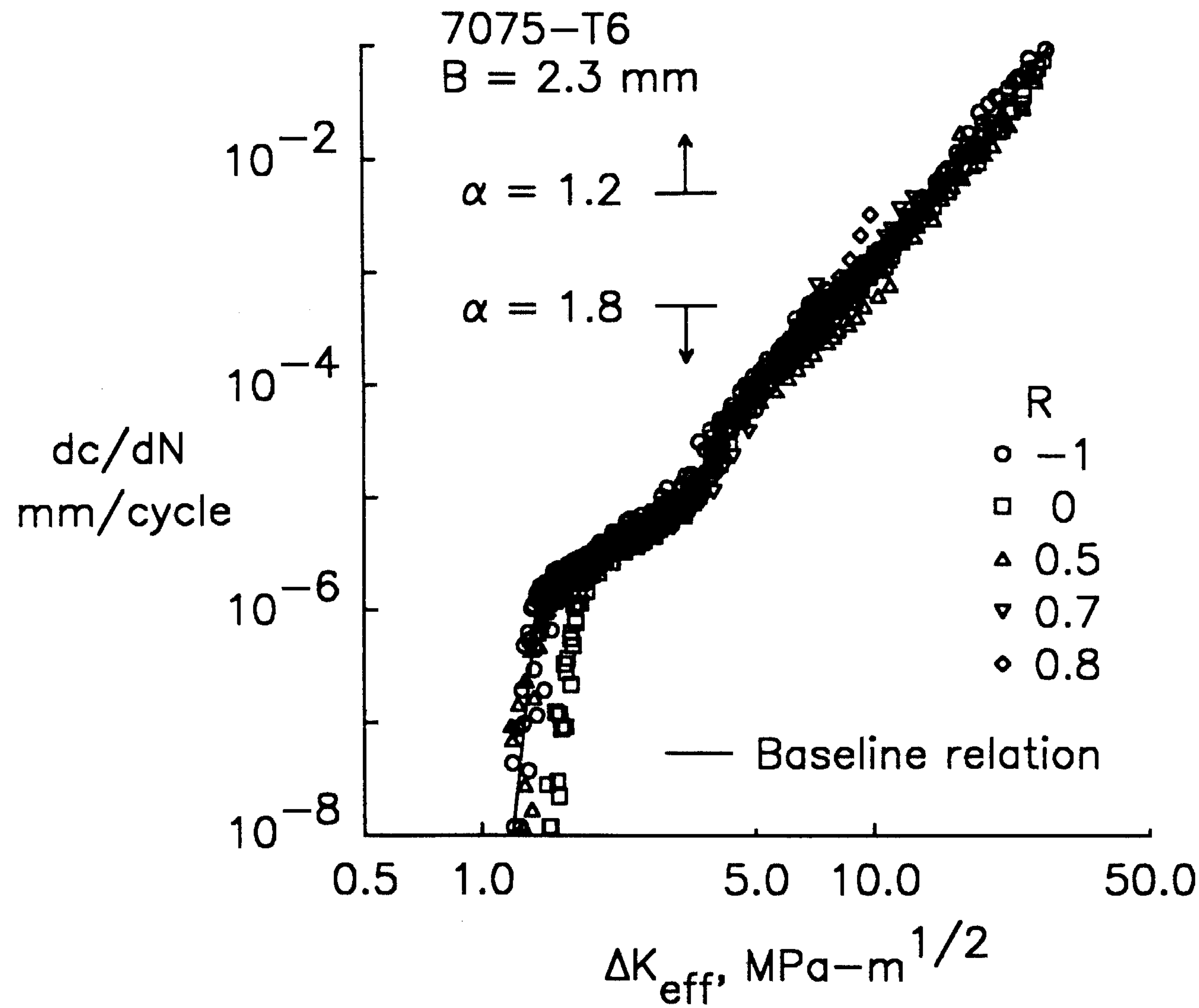


Figure 2(b).- Correlation of ΔK_{eff} against rate for various stress ratios using a plasticity-induced closure model analysis.

E. Computer Systems

FASTRAN was designed to be a research program, rather than a production program, due to the excessive computer time and cost involved in running the program. However, in the last decade, major advancements made in computer science and some modifications made in the code are making implementation of FASTRAN-II more practical. The computer time is directly related to the number of cycles required to grow a crack from an initial size to failure. Thus, crack-growth predictions under low stress levels will require more time than under high stress levels for the same initial crack length. The current version, FASTRAN-II, is written in FORTRAN-77 and executes on both mainframe and personal computers using a Unix operating system.

A CONVEX-C210 computer was used to generate the crack-growth predictions made on the example problems included in this manual. The CONVEX-C210 uses the UNIX-based operating system CONVEX UNIX Version 7.1. If the source program is denoted as 'fastran2.f', the program can be compiled on a CONVEX computer using the fc compiler statement:

```
fc -O2 -o fastran.ex fastran2.f
```

The executable program is denoted as 'fastran.ex'. The executable program runs about three times faster on a CONVEX computer under the -O2 option (scalar and vector optimization) than under normal compilation. The IMPLICIT REAL*8 (A-H,O-Z) statement was used to make all operations double precision; all intrinic functions are also used in double precision. The program is executed interactively by

```
fastran.ex < infast &
```

where 'infast' is a file containing the analysis input data filename 'infile' on the first line and the output filename 'outfile' on the second line. The program has internal timing statements using the SECONDS() command to time a particular job and to terminate execution for each input problem, if the user specified time limit is exceeded. The timing statements can be removed if the SECONDS() command is not available.

On a Personal Computer (IBM PS/2 Model 80 with an 80387 math coprocessor), the program 'fastran2.f' had to be subdivided into the main program and several sub-programs to compile using the Microsoft FORTRAN compiler (Version 4.01). (The comment on all WRITE(6,...) statements can be removed to activate some output to the screen. These write statements are used to verify program execution. The complete output file is 'outfile'.) The program excution times on the PC were about 60 times slower than those using the optimized program on the CONVEX computer.

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III. USER GUIDE FOR FASTRAN-II

A. Introduction

A line-by-line explanation of the input data for FASTRAN-II is presented herein. Each of the parameters used in the input data file is defined and explained. The input data to the program is listed in Sections B.1 to B.17. The data are input in free format unless otherwise stated. Several problems can be solved during each computer run by placing input data files from Sections B.1 to B.17 in series. A flow chart of FASTRAN-II is given in Section IV and a Quick Reference Guide for the Analysis (Input Data) File is given in Section V. The input and output data files for ten example problems are given and discussed in Section VI. These examples problems cover many of the options available in FASTRAN-II.

B. Analysis (Input Data) File

1. Problem Title

READ TITLE(20)
FORMAT (20A4)

Any 80-character title describing the problem. If TITLE(1) = HALT, then the computer run is terminated.

2. Spectrum Filename and Time Limit

READ SPECTRA, TLIMIT
FORMAT (A10,E10.3)

SPECTRA is the filename of the spectrum loading file (used only for NFOPT = 5, 8 and 9). For other NFOPT values, create and use a dummy file and filename, such as 'cstamp' (see example problem 1).

TLIMIT is the time limit in CPU seconds allowed for the problem.

3. Material

READ MAT
FORMAT (20A4)

Any 80-character description of the material.

4. Material Tensile Yielding Properties

READ SYIELD, SULT, E, ETA, ALP, NALP, NEP, BETA
FORMAT (*)

SYIELD = Yield stress (0.2 percent offset)

SULT = Ultimate tensile strength

E = Elastic modulus

ETA = 0 for plane stress (normally used)
= Poisson's ratio for plane strain

ALP = Constraint factor
= 1 Plane-stress condition
= 1.73 Irwin's plane-strain condition
= 3 Plane-strain condition

See references 3 and 9 for procedures to obtain the value of ALP for a particular material, thickness, and test condition.

NALP = 0 Constraint factor (ALP) is constant as input

= 1 Constraint factor is variable (ALP is computed by the program, see section 8, and refs. 8 and 11)

The crack-growth relation, ΔK_{eff} (or $\Delta\bar{K}_{eff}$) against dc/dN or da/dN, must have been obtained using the same constraint factor as specified by the NALP option. Section VII presents a user guide for DKEFF, a program to determine the effective stress-intensity factor against crack-growth rate relation for either NALP option.

NEP = 0 Effective stress-intensity factor is elastic

= 1 Effective stress-intensity factor is modified for plastic yielding at the crack tip by adding one-quarter of the cyclic plastic zone to the crack length (see eqn.(11)). (Note: The plasticity corrected stress-intensity factor in FASTRAN-II is different than that used in references 5 and 8. A closure corrected "cyclic" plastic zone size is used instead of the maximum plastic zone size.)

= 2 Effective stress-intensity factor is modified for plastic yielding at the crack tip by adding one-quarter of the monotonic plastic zone to the crack length ($d = c + \rho/4$) in equation (11), see reference 10.

BETA = Constraint factor on compressive yielding; Compressive yield stress = - BETA*SFLOW (BETA is usually set equal to unity; option has not been completely evaluated)

The flow stress, SFLOW, computed in the program is given by the average between the yield stress and ultimate tensile strength. KOPEN is used to select the method of calculating the crack-opening stress, SO. For KOPEN = 0, SO is computed from crack-surface displacements. For KOPEN = 1, SO is computed from contact stress-intensity factors. Under constant-amplitude loading, very little difference in SO is observed between KOPEN = 0 or 1. But under variable-amplitude loading, some differences are observed. KOPEN is automatically set in the program. The current version of FASTRAN-II has KOPEN = 1. The user can make KOPEN = 0 to activate the crack-surface displacement option. (The crack-opening stress equations in the Theoretical Manual, equations (5)-(7), apply for either value of KOPEN.)

5. Fatigue-Crack Growth Rate Option

```
READ  IRATE
FORMAT (*)
```

IRATE = 1 da/dN is equal to dc/dN as a function of ΔK_{eff}

= 2 da/dN and dc/dN have different ΔK_{eff} relations

The crack depth, a, is always measured with respect to plate thickness (t) and crack length, c, is measured in the plate width (w) direction.

<u>Repeat sections 6 to 7 IRATE times (J = 1 to IRATE).</u>

6. Fatigue-Crack Growth Rate Equation and Fracture Properties

```
READ  C1(1,J), C2(1,J), C3(J), C4(J), C5(J), KF, M
FORMAT (*)
```

C1(1,J) = Crack-growth coefficient for property J, C_1

C2(1,J) = Crack-growth power for property J, C_2

C3(J) = Threshold constant, C_3

C4(J) = Threshold constant, C_4

C5(J) = Cyclic fracture toughness or limiting value of maximum stress-intensity factor, C_5

J = 1 Properties in crack length c-direction
= 2 Properties in crack depth a-direction

KF = Elastic-plastic fracture toughness, K_F (see ref. 12)

M = Fracture toughness parameter, $0 \leq m \leq 1$ (see ref. 12)

<u>Constant-Amplitude Crack-Growth Rate Equation [2]</u>

$$dc/dN \text{ (or } da/dN) = C_1 \, \Delta K_{eff}^{C_2} \, [1 - (\Delta K_0/\Delta K_{eff})^2]/[1 - (K_{max}/C_5]^2 \qquad (15)$$

where

$$\Delta K_o = C_3 \, (1 - C_4 S_{min}/S_{max}) = C_3 \, (1 - C_4 R) \qquad (16)$$

$$K_{max} = S_{max} \sqrt{\pi c} \;\; F \qquad (17)$$

and

$$\Delta K_{eff} = (S_{max} - S_x) \sqrt{\pi c_x} \quad F \tag{18}$$

$S_x = S_o'$ if S_o' is greater than S_{min}, otherwise $S_x = S_{min}$

S_{min} = Minimum applied stress

S_{max} = Maximum applied stress

S_o' = Crack-opening stress

c_x = Current crack length (c) plus rate (dc/dN) per cycle

F = Boundary-correction factor (F is computed in Subroutine BCF)

K_{max} = Maximum stress-intensity factor

ΔK_o = Effective stress-intensity factor threshold (eq. (16))

Note that equation (16) is slightly different than that used in references 2 and 3. Caution should be exercised when using thresholds. Information obtained on thresholds [5] may make many of the thresholds invalid for small cracks.

Fracture Criterion (see ref. 12)

Failure occurs when $K_{max} \geq K_{Ie}$

$$K_{Ie} = \mu \, K_F \, (1 - m \, S_n/S_u) \tag{19}$$

where

$\mu = 1$ for $S_n \leq \sigma_{ys}$

$\mu = \sigma_{ys}/S_n$ for $\sigma_{ys} < S_n < \sigma_u$

S_n = Net-section stress (computed from applied stress)

σ_{ys} = Yield stress (0.2 percent offset)

σ_u = Ultimate tensile strength

S_u = Net-section stress to produce plastic hinge

K_F = Elastic-plastic fracture toughness

m = Fracture toughness parameter ($0 \le m \le 1$)

(m = 0 is for LEFM analysis; m = 1 is for very ductile materials; see reference 12)

Fracture can be simulated in three different ways.

1. Using the crack-growth rate equation (eq. (15)), failure occurs if $K_{max} > C5$.

2. The Two-Parameter Fracture Criterion [12], K_F and m, can also be used. Both conditions: $K_{max} > C5$ and $K_{max} > K_{Ie}$ are checked. Failure occurs if any of the two conditions are satisfied. [Set either C5 or KF to very large values (999.) to deactivate.]

3. Failure occurs under any option if the plastic-zone size (ρ) from the Dugdale model exceeds the remaining uncracked ligament (or net section).

7. Fatigue-Crack Growth Rate Table (see ref. 5)

a. READ NTAB, NDKTH
FORMAT (*)

NTAB = 0 Program uses crack-growth rate equation (eq. (15))

= Value greater than one indicates number of data points used to describe crack-growth rate data for tabular input (table must contain at least two data points)

If NTAB > 1 then:

NDKTH = 0 $dc/dN = f(\Delta K_{eff})$ with no crack growth if $\Delta K_{eff} < \Delta K_o$

= 1 $dc/dN = g(\Delta K_{eff} - \Delta K_o)$

If IRATE = 1, da/dN and dc/dN have same ΔK_{eff} relation

If IRATE = 2, da/dN and dc/dN have different tabular input for ΔK_{eff} relations

For NTAB > 1, input table (I = 1 to NTAB)

b. READ DKETAB(I,J), CGRTAB(I,J)
FORMAT (*)

DKETAB(I,J) = Effective stress-intensity factor range (ΔK_{eff})

CGRTAB(I,1) = Crack-growth rate (dc/dN) at DKETAB(I,1)

CGRTAB(I,2) = Crack-growth rate (da/dN) at DKETAB(I,2)

Restriction: DKETAB(I,J) must not be equal to DKETAB(I+1,J), no segments with infinite slope allowed.

The ΔK_{eff} and dc/dN (or da/dN) relationships may be independent of stress ratio (R) if the proper constraint factor (ALP) has been used.

Thresholds:

The ΔK_{eff}-thresholds are accounted for in the analysis by using equation (16). A crack will not grow if ΔK_{eff} is less than ΔK_o.

Fracture:

Fracture can be simulated in two different ways.

1. Using the crack-growth rate table (section 7), the Two-Parameter Fracture Criterion is used (see section 6.b). Failure occurs if $K_{max} > K_{Ie}$. [Note that C5 in the crack-growth rate equation (eq. 15) is not used.]

2. Failure occurs under any option if the plastic-zone size exceeds the remaining uncracked ligament (or net section).

If IRATE = 2, repeat sections 6 to 7, otherwise continue.

If IRATE = 1, the crack-growth rate properties in the a- and c-directions are automatically set equal to each other, that is C1(I,1) = C1(I,2), C2(I,1) = C2(I,2), C3(1) = C3(2), C4(1) = C4(2) and C5(1) = C5(2). When the tabular input is used, C1(I,J) and C2(I,J) (coefficient and power) are computed in Subroutine MATPROP for linear segment I and property J and these values are used in Subroutine RATE.

8. Crack Growth Rates at Transition (NALP = 1 option only)

READ RATE1, ALP1, BETA1, RATE2, ALP2, BETA2
FORMAT (*)

If NALP = 0 No input is required, go to section 9.

If NALP = 1 RATE1 is the crack-growth rate near the start of transition from flat-to-slant growth (ALP = ALP1 and BETA = BETA1 for rates less than RATE1). RATE2 is the crack growth rate near the end of the transition from flat-to-slant growth (ALP = ALP2 and BETA = BETA2 for rates greater than RATE2). For rates (RATES) between RATE1 and RATE2:

$$\mathrm{ALP} = \mathrm{ALP2} + (\mathrm{ALP1} - \mathrm{ALP2}) \left\{ \frac{\log(\mathrm{RATES}) - \log(\mathrm{RATE2})}{\log(\mathrm{RATE1}) - \log(\mathrm{RATE2})} \right\} \tag{20}$$

$$\text{BETA} = (\text{BETA2} - \text{BETA1}) \left\{ \frac{\text{ALP} - \text{ALP1}}{\text{ALP2} - \text{ALP1}} \right\} + \text{BETA1} \tag{21}$$

where ALP is calculated from equation (20).

These equations are in the main program under the VARIABLE CONSTRAINT section. BETA is the constraint factor on compressive yielding. The influence of BETA on crack-opening stresses has not been studied. Thus, BETA1 and BETA2 should be set equal to unity.

9. Data Output Options

READ NIPT, NPRT, LSTEP, NDKE, DCPR
FORMAT (*)

NIPT = 0 Internal print off

= Value greater than zero indicates output at a half-cycle after "NIPT" crack-growth increments. Applied stress, crack length, element sizes, element displacements, element stresses, and maximum plastic-zone size are printed out at LSTEP applied load increments during each half-cycle.

NPRT specifies frequency of crack-length-against-cycles output.

= Zero or negative number indicates crack-length-against-cycles output at specified crack-growth increment (DCPR)

= One or greater, indicates crack-length-against-cycles output at every "NPRT"th crack-growth (Δc^*) increment in the closure model.

For either value of NPRT, the program prints the following: total blocks (or flights) applied (NFLT), crack length (C) or crack length minus hole radius (C' - RAD), crack-depth-to-plate-thickness (A/T) ratio, number of cycles (N), constraint factor (ALP), crack-opening stress-intensity factor ratio (KO/KMAX), either the stress-intensity factor range (DKC) or effective stress-intensity factor range (DKEC) at C, and the crack-growth rate (DC/DN). For surface and corner cracks, the stress-intensity factor range (DKA) or effective stress-intensity factor range (DKEA) at A and DA/DN are also printed.

LSTEP = Number of load steps from minimum to maximum load during NIPT printout (usually set equal to one). Use values greater than one to study how the crack surfaces open. This option gives the contact stresses and stresses in the plastic zone during cyclic loading.

NDKE = 0 Print out elastic stress-intensity factor ranges

= 1 Print out effective stress-intensity factor ranges

DCPR = Crack-growth increment at which crack-length-against-cycles information are printed out

10. Specimen Type and Loading (see Figs. 3 and 4)

READ NTYP, LTYP, LFAST, NS, NFOPT, INVERT, KCONST
FORMAT (*)

NTYP = Specimen type

= -11 Periodic array of symmetric through cracks at holes under S
= -10 Periodic array of symmetric through cracks at holes under pin-loading (P), remote stress S=P/(2wt) and moment (γS)
= -9 Corner crack at edge of semi-circular edge notch under S
= -8 Through crack at semi-circular edge notch under S
= -7 Surface crack at center of semi-circular edge notch under S
= -6 Two symmetric surface cracks at center of hole under S
= -5 One surface crack at center of hole under S
= -4 Two symmetric through cracks at a hole under S
= -3 One through crack at a hole under S
= -2 Two symmetric corner cracks at a hole under S
= -1 One corner crack at a hole under S
= 0 Surface crack under tension (S) and bending (S_b)
= 1 Center crack tension under S
= 2 Compact specimen (Input: S = P/(wt))
= 3 Single-edge crack tension under S
= 4 User specified crack configuration (see discussion below)
= 5 Through crack in pressurized cylinder (Input: S = p*radius/t)
= 6 Corner-crack in bar specimen (circular crack, a = c) under S

For surface and corner cracks, the crack-opening stress is assumed to be constant along the crack front. Cracks are grown in two directions--at the maximum depth point and at the point of the intersection of the crack with the free surface (see ref. 13). The analysis terminates if the limits on the stress-intensity factor equations are exceeded. (NTYP must be negative for cracks growing from a hole or notch.)

The user can define crack configuration of interest by using NTYP = 4. The user must program the stress-intensity boundary-correction factor equations for the desired crack configuration in Subroutine SIF4 and re-compile the program. The stress-intensity factor solution must be in the form

$K = S \sqrt{\pi c}\, F_c$ for a through crack and

$K_a = S \sqrt{\pi c}\, F_a$ and $K_c = S \sqrt{\pi c}\, F_c$ for surface or corner cracks. F_a and F_c are the correction factors at the crack-depth location (F_a= FA) and at the surface location (F_c= FC). S is a characteristic stress used to defined the stress-intensity factor and is input in sections 14 and 16. The crack length c must be measured in the width (w) direction and crack depth is measured in the thickness (t) direction. The current configuration defined in Subroutine SIF4 is a through crack in a bend bar, see Figure 4(p).

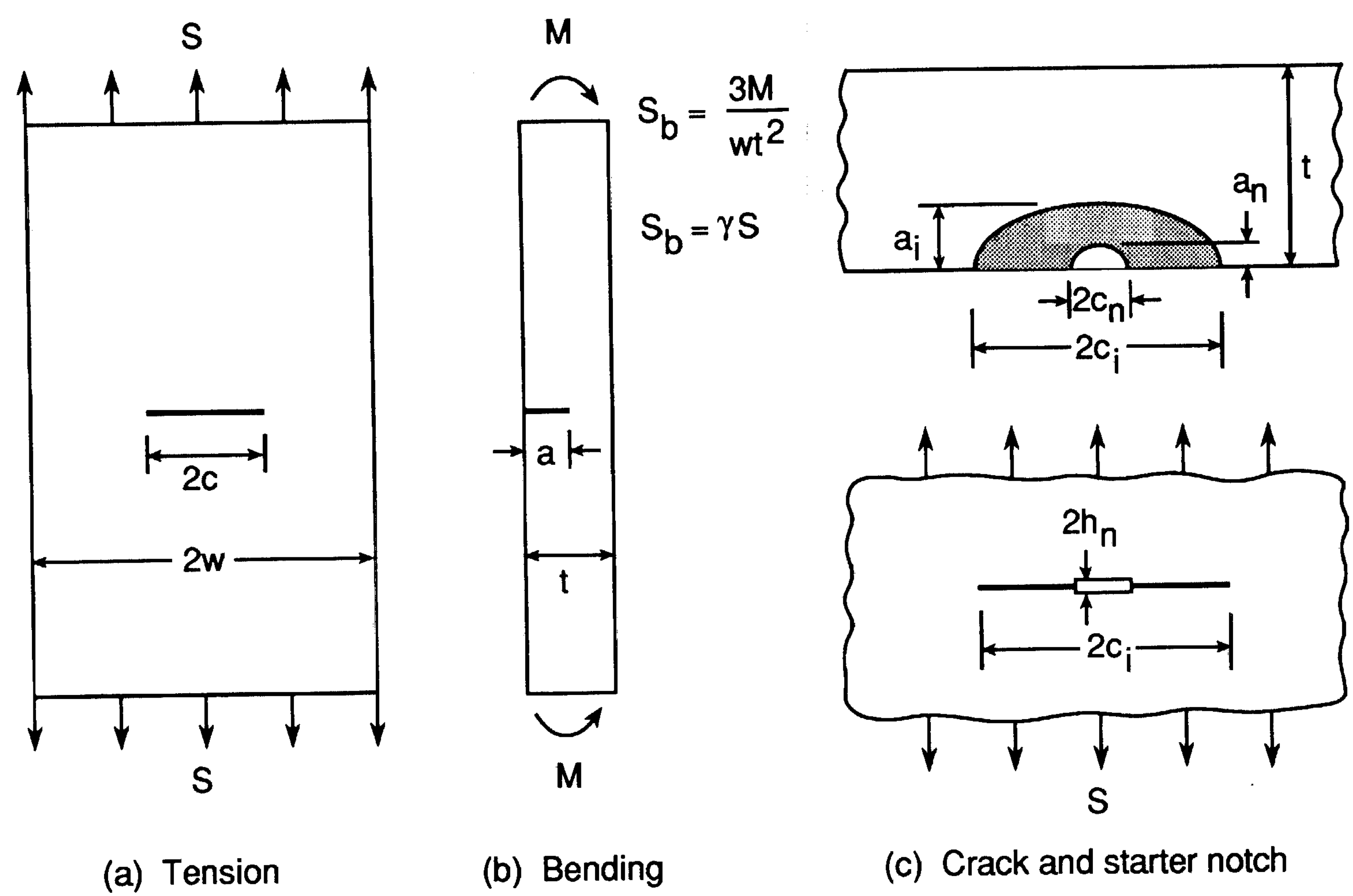


Figure 3.- Type of loading and crack starter notch details.

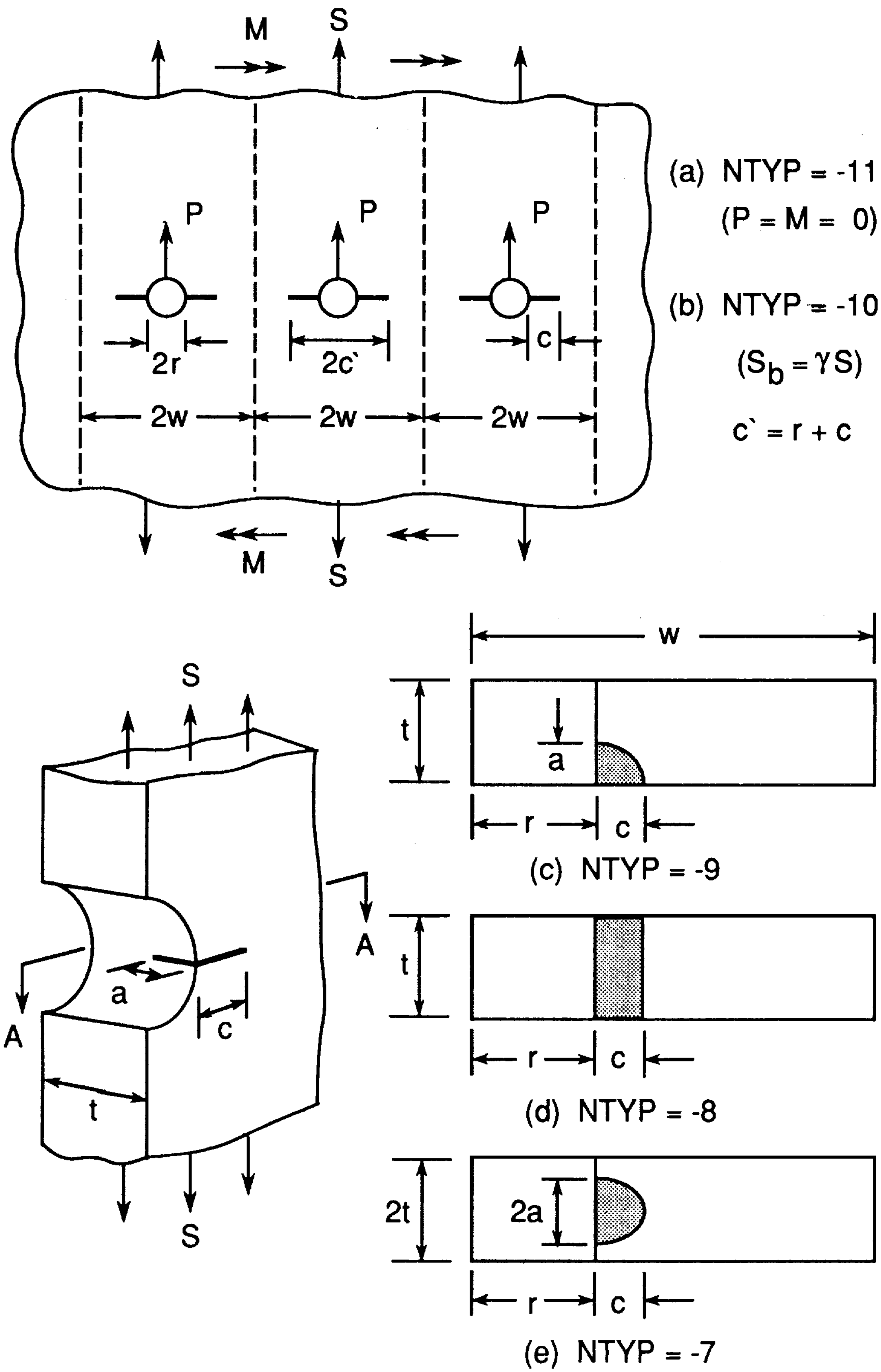


Figure 4.- Crack configurations analyzed.

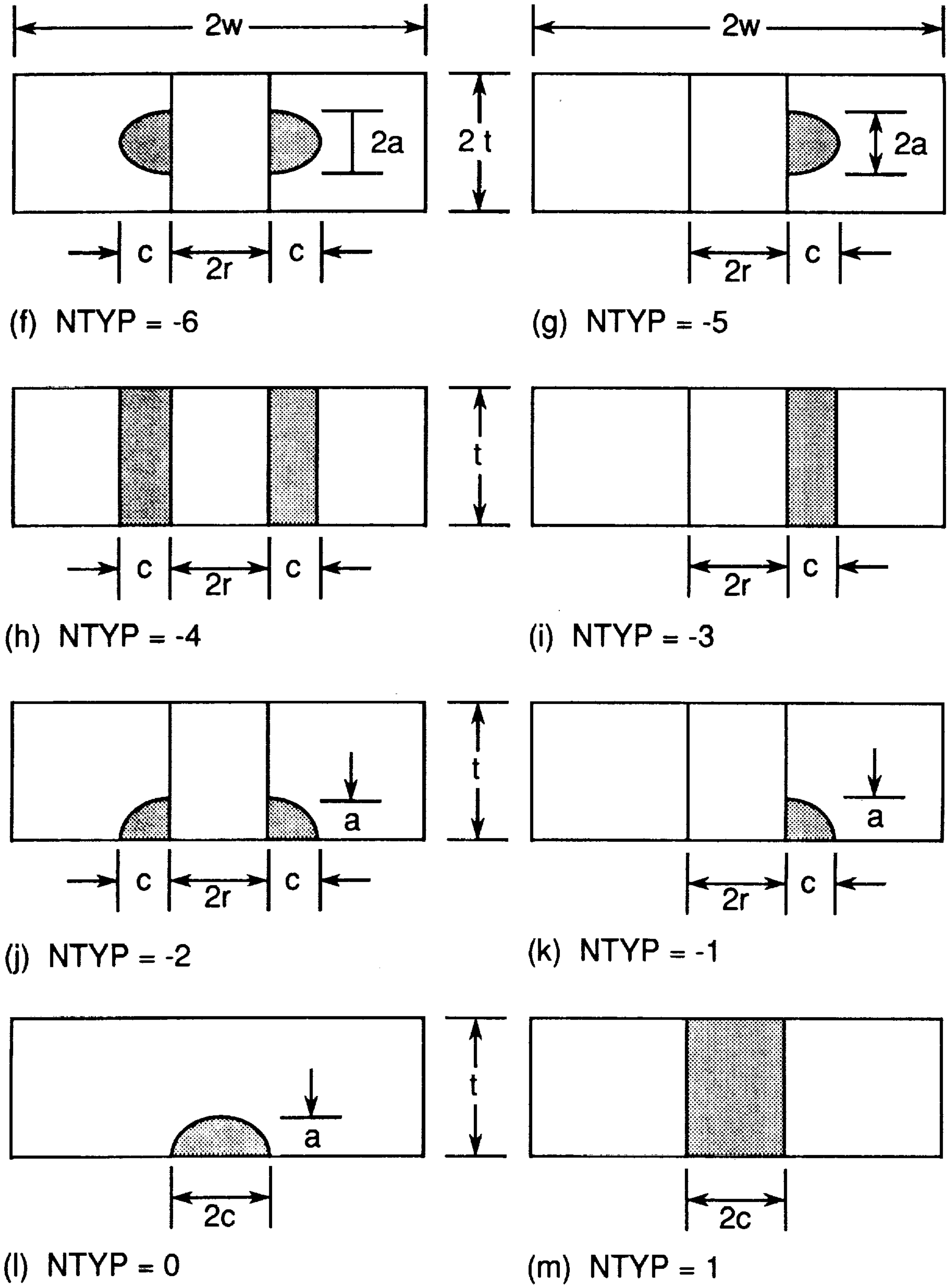


Figure 4.- Crack configurations analyzed (continued).

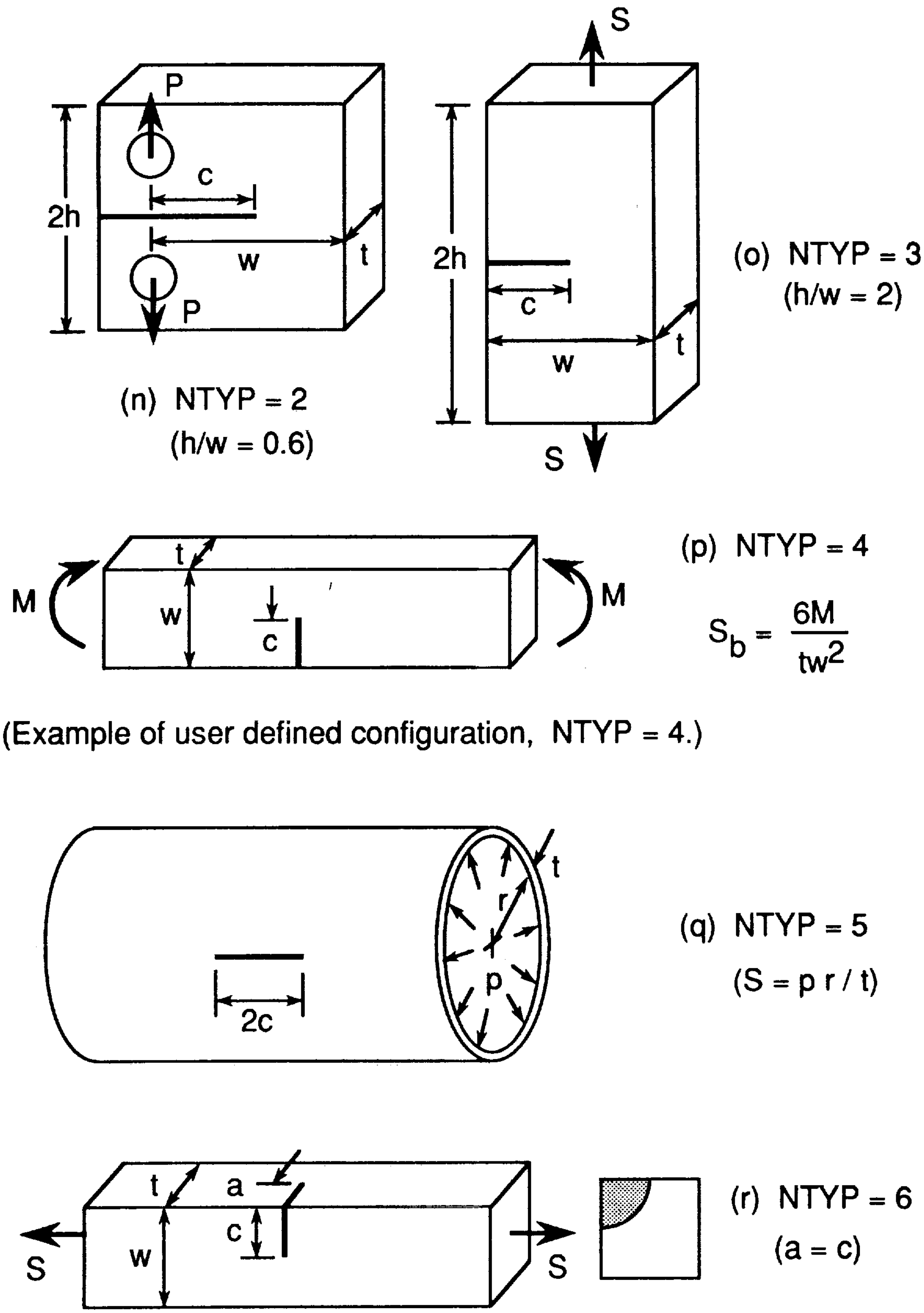


Figure 4.- Crack configurations analyzed (concluded).

LTYP = Type of loading (currently applies only for NTYP = 0)

= 0 Remote tension (S)

= 1 Remote bending (input stress on outer surface, S_b)

= 2 Combined tension (S) and bending (γS)
(input S and γ; bending stress on outer surface is γS)

LFAST = 0 Normal crack-closure model (S_o' is computed from the analytical crack-closure model for NTYP = 1 or -4 and the opening stresses are assumed to apply for the other crack configurations. NTYP = 1 is used for NTYP $\geq$ 0; and NTYP = -4 is used for all negative NTYP.)

= 1 Uses an equivalent crack-opening stress, $\bar{S}_o$ (SOBAR), for $c \geq c_{max}$ and NFLT > 2*MAXSEQ. The c_{max} value is equal to the initial crack length, CI, plus 10 times the expected maximum cyclic plastic-zone size. MAXSEQ equals the total number of blocks (or flights) in a sequence to be repeated. NFLT is the block or flight counter. The sequence to be repeated must be repeated at least two times before the equivalent crack-opening stress concept is activated. SOBAR is calculated in the program by a damage-weighted average during the second application of the full sequence as:

$$\bar{S}_o = (\Sigma\ \Delta c\ S_o'\ W_{df})/(\Sigma\ \Delta c\ W_{df}) \quad \text{where } W_{df} = 1 - \Delta S_{eff}/\Delta S$$

= 2 Linear cumulative damage calculations using S_o' equation for constant-amplitude loading [9] (equations are programed in Subroutine SOEQN). The crack-opening stress equations (4)-(6) must have been used to obtain the effective stress-intensity factor range against crack-growth rate relationship.

= 3 Uses a constant crack-opening stress concept for precracking (Subroutine SOEQN) and for block (or flight) loading (Subroutine SOFLY). In Subroutine SOFLY, the highest and lowest stresses in the total block (or flight) history are used with the constant-amplitude crack-opening equations [9] to calculate the "constant" crack-opening stress. Again, the crack-opening stress equations must have been used to obtain the effective stress-intensity factor range against crack-growth rate relation. (<u>Caution</u>: This option has not been completely evaluated. For short spectra, that is, spectra that are repeated quite often, this option may give good, inexpensive predictions if the proper constraint factor has been used. For spectra, such as TWIST or FALSTAFF, this is not a good option.)

= 4 Same as LFAST = 3 option, except that the constant crack-opening stress for block (or flight) loading is manually input as an S_o'/S_{max} ratio. The integer NRC must be set equal to -1 and the DVALUE input is the crack-opening stress ratio (see section 15).

NS = Number of elements used to define starter notch; elements are of equal width. These elements are used if the notch surfaces come into contact. The minimum value of NS is 1 for cracks growing from a starter notch; and the minimum value of NS is 2 for cracks growing from a starter notch at a hole.

NFOPT = Block (or flight) loading option

= 0 Constant-amplitude loading

= 1 Blocks (or flights) are applied by user specified periodic sequence (NSQ(I) = periodic sequence of block I)

= 2 TWIST flight-load sequence [14] (SMEAN = mean stress)
Options:
INVERT = 0 or 1 normal TWIST loading
= 2 maximum stress clipped above Level II
= 3 maximum stress clipped above Level III
= 4 maximum stress clipped above Level IV
= 5 maximum stress clipped above Level V

(Level I is the highest stress in TWIST; Level II is second highest; Level III is third highest; and etc. Clipping above Level III means that a cycle in TWIST that exceeds Level III is reduced to Level III but the cycle is applied.)

= 3 Mini-TWIST flight-load sequence [15] (SMEAN = mean stress)
INVERT options same as those for TWIST (see above)

= 4 FALSTAFF flight-load sequence [16]
Options:
INVERT = 0 normal FALSTAFF sequence (SPEAK = highest stress)
= 1 inverted FALSTAFF sequence (SPEAK = lowest stress; mirror image of FALSTAFF about zero)

= 5 Space Shuttle load sequence (SPEAK = highest stress)
Options:
INVERT = 0 full shuttle spectrum from "stsn" file
= 1 short shuttle spectrum from "stsn" file

(The short shuttle spectrum have stress ranges in the full shuttle spectrum grouped together in take-off and landing sequence, see file 'stsn'.)

= 6 Gaussian (Irregularity factor = 0.99) load sequence [17]
(SPEAK = highest stress; SMEAN = mean stress)

(Irregularity factor of 0.99 is nearly an R = -1 spectrum for a mean stress of zero.)

= 7 Felix-28 flight-load sequence [18] (SPEAK = highest stress)

(The spectrum generator for Felix-28 is the same generator for the full Felix, Helix and Helix-32 spectra. The data statements in Subroutine HIXFIX need to be replaced or modified for these other spectra, see reference 18.)

= 8 Spectrum read from tape as a list of stress points.
Input: Total number of stress points (S_{max} and S_{min}) in spectra; highest and lowest stress values in list;
INVERT = 0 stresses are max, min,..., max, min;
INVERT = 1 stresses are min, max,..., min, max;
if INVERT = 1 spectrum is reordered and written to file 'spectra8' with INVERT = 0 input; re-run program with spectra filename equal spectra8; SPEAK = highest stress desired.

= 9 Spectrum read from tape as flight-by-flight sequence.
Input: Total number of flights in spectra; highest and lowest stress values in total spectra;
INVERT = 0 stresses are max, min,..., max, min;
INVERT = 1 stresses are min, max,..., min, max;
if INVERT = 1 spectrum is reordered and written to file 'spectra9' with INVERT = 0 input; re-run program with spectra filename equal spectra9; SPEAK = highest stress desired. For each flight, input flight number, number of stress points in flight, and list of stress values.

INVERT = Value between 0 and 5 to modify or select special feature of spectrum loading (see notes under NFOPT options above)

KCONST = 0 Normal value to apply stress or load as external loading

= 1 Apply stress-intensity factor for loading; input K_{max} and K_{min} instead of stress; only for NTYP = 1 or 2.

11. Specimen and Crack Starter-Notch Dimensions (see Fig. 3)

```
READ  W, T, CI, AI, CN, AN, HN, RAD
FORMAT (*)
```

W = One-half width, w (or width for NTYP = 3, 2, -7, -8 and -9)

T = Thickness, t (one-half thickness for NTYP = -5, -6 or -7)

CI = Initial crack length, c_i' (crack length plus hole or notch radius, $c_i + r$, for NTYP = -1 to -11, otherwise $c_i' = c_i$)

AI = Initial crack depth, a_i, for surface or corner crack (AI is automatically set equal to T for a through crack)

CN = Starter notch length, c_n' (notch length plus hole or notch radius, $c_i + r$, for NTYP = -1 to -11, otherwise $c_i' = c_i$)

AN = Starter notch depth, a_n, for surface or corner crack (AN is automatically set equal to T for a through crack)

HN = Starter notch height, h_n

RAD = Radius (r) of circular hole located in center of specimen or radius of semi-circular edge notch

(For NTYP > 0, RAD is automatically set equal to zero.)

See Figures 3 and 4 for specimen nomenclature. A through crack of length c (or c') is assumed when crack depth, a, is equal to plate thickness, t, for a surface crack, corner crack, surface crack (or corner crack) at a hole or notch configurations.

12. Final Crack Length Requested

```
READ  CF
FORMAT (*)
```

CF = Final crack length, c_f', desired
(analysis will terminate when crack length exceeds c_f')

13. Special Input for Various Crack Configurations

a. If NTYP = 0 (with LTYP = 2) or NTYP = -10 then:

```
READ  GAMMA
FORMAT (*)
```

GAMMA = Ratio of outer fiber bending stress to remote tensile stress

b. If NTYP = -7, -8 and -9 then:

```
READ  XKT, NBCF
FORMAT (*)
```

XKT = Elastic stress-concentration factor (see NBCF options)

NBCF = 0 Uniform stress (h/w = 2; r/w = 1/16; XKT= 3.17)
1 Uniform displacement (h/w = 1.5; r/w = 1/16; XKT= 3.15)
2 Uniform displacement (h/w = 2; r/w = 1/16; XKT= 3.17)
3 Uniform displacement (h/w = 3; r/w = 1/8; XKT= 3.30)

Caution: These particular crack configurations should have the stress-concentration factors (XKT) input as specified. The program will accept the XKT value as input. The stress-concentration factors are based on gross stress.

c. If NTYP = 5 then:

READ RADIUS
FORMAT (*)

RADIUS = Radius of pressurized cylinder

14. Input Constant-Amplitude Loading to Initiate Crack from Starter Notch

READ SMAX, SMIN
FORMAT (*)

The crack grows from an "initial notch size" (c_n or CN) to the "initial crack length" (c_i or CI) under constant-amplitude loading. The number of cycles are counted but cycles are reset to zero at the end of the initiation stage ($c = c_i$). When $c = c_i$, the current value of crack depth, a, may not be equal to a_i. The current crack depth is then reset to the input value of a_i. The crack-opening stress computed in the initiation stage is used at the start of the Primary Fatigue Loading in the model. (If CN is set equal to CI, then the crack configuration is not precracked. This input is required but the values are not used in the program.)

15. Special Input for Proof Test or Constant Crack-Opening Stress Concept

READ NRC, DVALUE
FORMAT (*)

NRC = 0 DVALUE not used

= 1 Proof test simulation for NTYP = 1 only, where DVALUE is the amount of crack extension from proof loading (first load application under primary fatigue loading). DVALUE is determined from other sources, such as a resistance-curve analysis. [Note: The value of crack extension during the proof stress can be computed from the program by setting NRC = 0 and putting the desired proof stress as the first load application under Primary Fatigue Loading, see next section. The first cycle is assumed to be applied under stroke control and the cracked body will not fail unless the plastic zone in the model exceeds the net section (see ref. 8).]

= -1 DVALUE is the crack-opening stress (S_o'/S_{max}) ratio manually input under the LFAST = 4 option and is determined from other sources.

DVALUE = Input value for NRC option (see above)

16. Input Primary Fatigue Loading

a. Constant- or Variable-Amplitude Loading (NFOPT = 0 or 1):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = Total number of blocks (or flights) in the sequence to be repeated

MAXBLK = Number of different blocks (or flights, such as 1st, 5th, 10th, etc.) that are used to compose load history. Each block or flight may be composed of various number of stress levels (maximum and minimum stress) Each stress level can have any number of cycles.

LPRINT = 0 Print option, not used for NFOPT = 0 or 1

MAXLPR = 0 Parameter not used for NFOPT = 0 or 1

Line 2: READ SCALE
FORMAT (*)

SCALE = Scales stress levels in all blocks (or flights)

SMAXP(I,J) = SCALE * SMAXP(I,J)
SMINP(I,J) = SCALE * SMINP(I,J)

Line 3: READ NBLK, NSL(I), NSQ(I)
FORMAT (*)

NBLK = Specific block (or flight) number (numbered consecutively and NBLK $\leq$ 7)

NSL(I) = Number of stress levels to define block (or flight) I

NSQ(I) = Periodic sequence of block (or flight) I, block or flight I is repeated every "NSQ" blocks or flights.

Line 4: READ SMAXP(I,J), SMINP(I,J), NCYCP(I,J)
FORMAT (*)

SMAXP(I,J) = Maximum applied stress of level J in block (or flight) I

SMINP(I,J) = Minimum applied stress of level J in block (or flight) I

NCYCP(I,J) = Number of cycles of level J in block (or flight) I

Maximum number of different blocks (or flights) I allowed is 5; maximum number of stress levels J allowed is 1205.

<u>Repeat line 4 for each stress level in block (or flight) I.</u>
<u>Repeat lines 3 and 4 for each block (or flight) until MAXBLK</u> is completed. The blocks (or flights) must be ordered in increasing periodic sequence (NSQ). In other words, BLOCK (or FLIGHT) 2 must have a larger NSQ value than BLOCK (or FLIGHT) 1, BLOCK (or FLIGHT) 3 must have a larger NSQ value than BLOCK (or FLIGHT) 2, etc.

Examples:

1. For constant-amplitude loading (NFOPT = 0), as shown in Figure 5(a):

```
MAXSEQ = MAXBLK = 1      LPRINT = 0     MAXLPR = 0
NBLK = NSL(1) = NSQ(1) = 1
  SMAXP(1,1) = Maximum applied stress, Smax
  SMINP(1,1) = Minimum applied stress, Smin
  NCYCP(1,1) = May be set equal to any number of cycles (normally set
               equal to 1000).  Program runs slightly faster if NCYCP
               is set equal to or greater than NMAX.  NMAX is the
               maximum number of cycles allowed before the "analytical"
               closure model is exercised.  NMAX is set to 1000 cycles
               in the program.
```

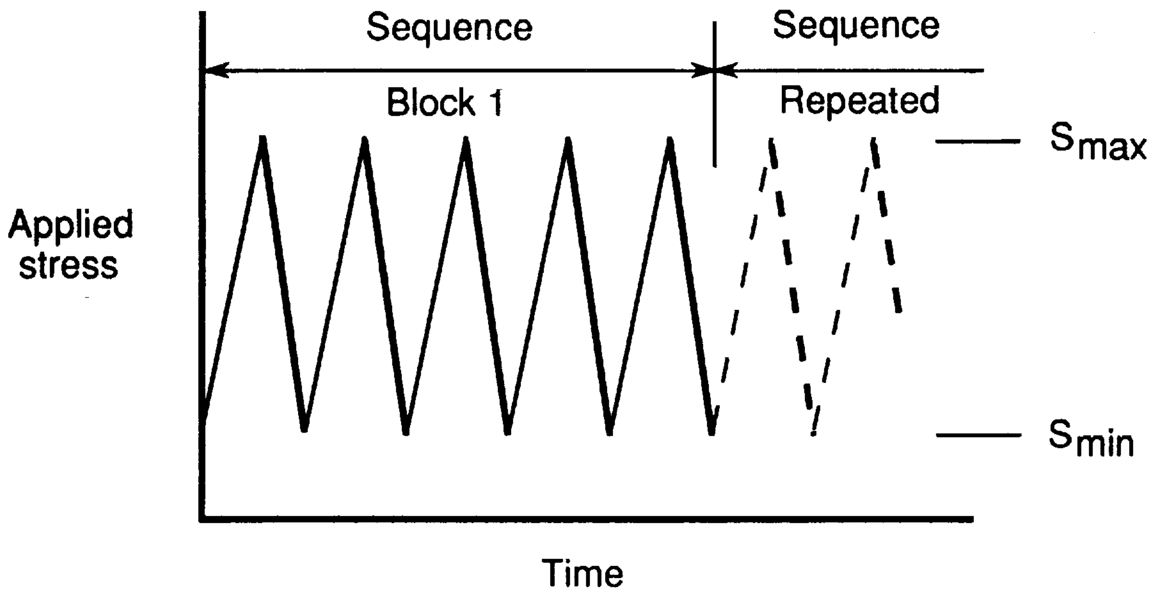
2. For variable-amplitude loading (NFOPT = 1), as shown in Figure 5(b):

```
MAXSEQ = 5     MAXBLK = 2     LPRINT = 0     MAXLPR = 0
NBLK = 1      NSL(1) = 2     NSQ(1) = 1
  SMAXP(1,1) = S1     SMINP(1,1) = S2     NCYCP(1,1) = 3
  SMAXP(1,2) = S1     SMINP(1,2) = S3     NCYCP(1,2) = 1
NBLK = 2      NSL(2) = 4     NSQ(2) = 4
  SMAXP(2,1) = S1     SMINP(2,1) = S2     NCYCP(2,1) = 2
  SMAXP(2,2) = S4     SMINP(2,2) = S5     NCYCP(2,2) = 1
  SMAXP(2,3) = S1     SMINP(2,3) = S2     NCYCP(2,3) = 1
  SMAXP(2,4) = S1     SMINP(2,4) = S6     NCYCP(2,4) = 1
```

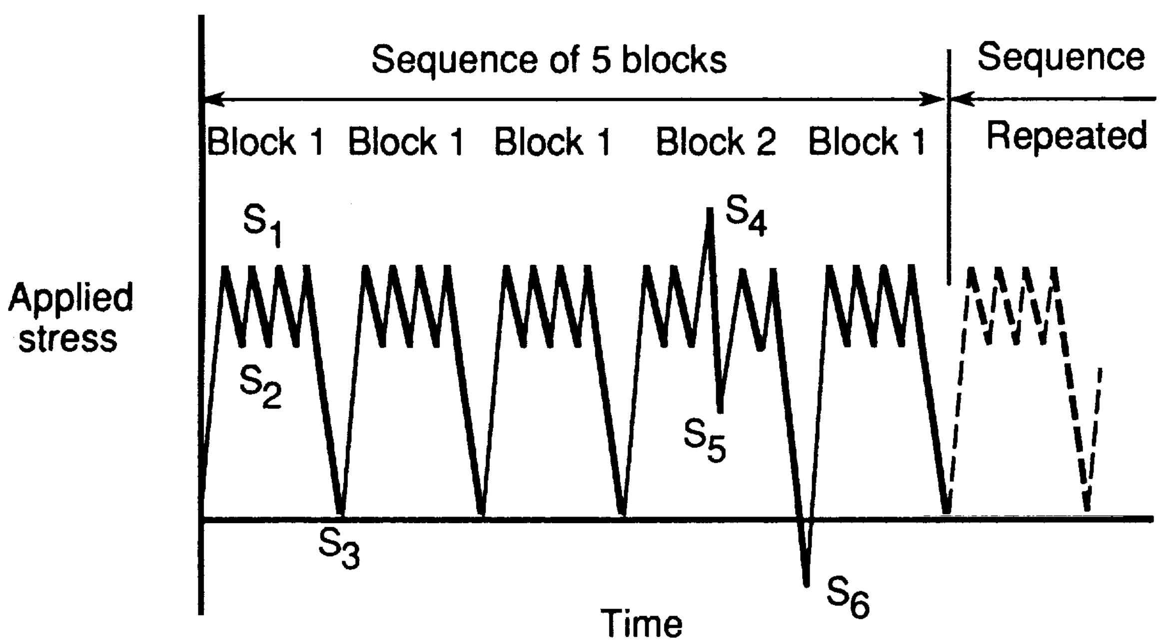
The unloading half-cycle, maximum to minimum stress, is used to set up the input data, as indicated by the heavy lines in Figure 5(b).

b. TWIST [14] or MINI-TWIST [15] Flight-Load Sequence (NFOPT = 2 or 3, respectively):

```
Line 1: READ  MAXSEQ, MAXBLK, LPRINT, MAXLPR
        FORMAT (*)

          MAXSEQ = 4000     MAXBLK = 10

          LPRINT = 0  No internal spectrum information printed
                   1  Print out flight numbers
                   2  Print out flight numbers, stress levels and
                      cycles (may result in large output file)
          MAXLPR =  Number of flights to be printed out

Line 2: READ  SMEAN
        FORMAT (*)

          SMEAN = Mean stress for TWIST or MINI-TWIST spectrum

                  Flight sequences and stress levels are computed
                  in Subroutine TWIST; program scales stresses to
                  desired stresses using SMEAN.
```



(a) Constant-amplitude loading



(b) Variable-amplitude loading

Figure 5.- Typical constant- and variable-amplitude loading.

c. FALSTAFF [16] Flight-Load Sequence (NFOPT = 4):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = MAXBLK = 200

LPRINT = 0 No internal spectrum information printed
1 Print out flight numbers
2 Print out flight numbers, stress levels and cycles (may result in large output file)
MAXLPR = Number of flights to be printed out

Line 2: READ SPEAK
FORMAT (*)

SPEAK = Highest stress in FALSTAFF spectrum (level 32)

Flight sequences and stress levels are computed in Subroutine FALSTAF; program scales stresses to desired stresses using SPEAK.

d. Space Shuttle Flight-Load Sequence (NFOPT = 5):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = MAXBLK = MAXLPR = 2

LPRINT = 0 No internal spectrum information printed
1 Print out stress levels and cycles in either full or short spectra.

Line 2: READ SPEAK
FORMAT (*)

SPEAK = Highest desired stress in Space Shuttle spectrum

Flight sequences and stress levels are computed in Subroutine SHUTTLE from 'stsn' file; program scales stresses to desired stresses using SPEAK.

e. Gaussian Load Sequence [17] (NFOPT = 6):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = MAXBLK = 839

LPRINT = 0 No internal spectrum information printed
1 Print out part of stress levels and cycles
MAXLPR = 4195 (only part of the spectrum is printed)

Line 2: READ SPEAK, SMEAN
FORMAT (*)

SPEAK = Highest stress desired in Gaussian spectrum
SMEAN = Mean stress desired in Gaussian spectrum

Flight sequences and stress levels are computed in Subroutine GAUSS with an irregularity factor of 0.99 (nealy R = -1); program scales spectrum to desired mean and highest desired stress.

f. Felix-28 [18] Helicopter Flight-Load Sequence (NFOPT = 7):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = 140 MAXBLK = 12

LPRINT = 0 No internal spectrum information printed
1 Print out flight numbers and levels
2 Print out spectrum tables, stress levels and cycles (may result in large output file)

MAXLPR = Number of flights to be printed out

Line 2: READ SPEAK
FORMAT (*)

SPEAK = Highest stress desired in Felix-28 spectrum

Flight sequences and stress levels are computed in Subroutine HIXFIX; program scales spectrum to desired stresses using SPEAK.

g. Spectrum Read from List of Stress Points (NFOPT = 8):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = MAXBLK = (NPOINTS-1)/2400 + 1

NPOINTS = total number of stress points in spectrum

LPRINT = 0 No internal spectrum information printed
1 Limited output of block numbers and cycles
2 Print out block numbers, stress levels and cycles (may result in large output file)

MAXLPR = Number of blocks to be printed out

Line 2: READ SPEAK
FORMAT (*)

SPEAK = Highest stress desired

Sequences and unit stress levels are read from SPECTRA filename; program scales stresses to desired stresses using SPEAK.

h. Spectrum Read from Flight-by-Flight Loading (NFOPT = 9):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR
FORMAT (*)

MAXSEQ = MAXBLK = NFLIGHTS

NFLIGHTS = total number of flights in spectrum

LPRINT = 0 No internal spectrum information printed
1 Limited output of flight numbers and cycles
2 Print out flight numbers, stress levels and cycles (may result in large output file)

MAXLPR = Number of flights to be printed out

Line 2: READ SPEAK
FORMAT (*)

SPEAK = Highest stress desired

Sequences and unit stress levels are read from SPECTRA filename; program scales stresses to desired stresses using SPEAK.

17. Input Variables for Load-Reduction Threshold Test

READ KTH, SMAXTH, RTH, CONST
FORMAT (*)

KTH = 0 No threshold test (normal program, applied stresses are obtain from section 16)

= 1 ASTM recommended practice (CONST = dK/dc/K)
For a given value of CONST, the percentage change in K is constant for equal increments of crack length. CONST must be equal to or greater than -80 m^{-1} or -2 in^{-1}.

= 2 Stress-intensity gradient procedure (CONST = dK/dc)
For a given value of CONST, the rate of change in ΔK is constant for equal increments of crack length.

= 3 Ten-percent load reduction procedure (CONST = dc)
For a given value of CONST, the load reduction is 10 percent of the previous load for equal increments of crack length.

SMAXTH = Maximum stress level at start of load-reduction test
RTH = Stress ratio for threshold test
CONST = Constant related to how the load is reduced during crack extension

A threshold test is restricted to a center-crack tension (NTYP = 1) specimen, under applied remote stress (KCONST = 0) and the normal crack-closure model (LFAST = 0) with NFOPT = 0.

The current maximum applied stress level is given by

KTH = 1: $S_{max} = \{K(c_i)/K(c)\ EXP[\ CONST\ (c - c_i)]\}\ SMAXTH$

KTH = 2: $S_{max} = [K(c_i) + CONST\ (c - c_i)]\ SMAXTH$

KTH = 3: $S_{max} = SMAXTH\ \ 0.9^{Int[(c - c_i)/CONST]}$

where K(c) and $K(c_i)$ are the stress-intensity factors evaluated at the current crack length, c, and at the initial crack length, c_i, respectively. The KTH = 1 and 2 methods are continuous functions and the KTH = 3 method is a step function. The minimum stress S_{min} is RTH times S_{max}.

<u>Repeat sections B.1 to B.17, to input another problem or input next problem title as HALT to terminate computer run (see section B.1).</u>

C. Spectrum Input Files

1. List of Stress Points (NFOPT = 8)

Line 1: READ TITLE
FORMAT (20A4)

Any 80-character title describing the spectrum.

Line 2: READ NPOINTS, MAXST, MINST, INVERT, LFORMAT
FORMAT (*)

NPOINTS = Number of stress points in total spectrum
MAXST = Highest stress point in total spectrum
MINST = Lowest stress point in total spectrum
INVERT = Value indicating order of stresses
= 0 $Smax_1$, $Smin_1$,..., $Smax_n$, $Smin_n$
= 1 $Smin_1$, $Smax_1$,..., $Smin_n$, $Smax_n$
LFORMAT = Specified format for stress values
= 1 FORMAT(20I4)
= 2 FORMAT(16I5)
= 3 FORMAT(10I8)

Note: Stress values must conform to the specified format field. Either 20, 16 or 10 stress values must be on all lines except the last line. The last line may have any number less than the specified format field.

Line 3: READ (NSIG(I), I=1,NPOINTS)
FORMAT (20I4, 16I5 or 10I8)

NSIG(I) = stress expressed as an integer

If INVERT = 1, the spectrum is read and the array NSIG is reordered to correspond to the INVERT = 0 option. A new spectrum file is generated named 'spectra8'. FASTRAN-II must then be run using the new spectrum filename.

2. Flight-by-Flight Loading (NFOPT = 9)

Line 1: READ TITLE
FORMAT (20A4)

Any 80-character title describing the spectrum.

Line 2: READ NFLIGHT, MAXST, MINST, INVERT
FORMAT (*)

NFLIGHT = Number of flights in total spectrum
MAXST = Highest stress point in total spectrum
MINST = Lowest stress point in total spectrum
INVERT = Value indicating order of stresses in flights
= 0 $Smax_1$, $Smin_1$,..., $Smax_n$, $Smin_n$
= 1 $Smin_1$, $Smax_1$,..., $Smin_n$, $Smax_n$

Line 3: READ JFLT(M), NUM, (NSIG(I), I=1,NUM)
FORMAT (*)

JFLT(M) = Flight number for flight m
NUM = Number of stress points in flight m
NSIG(I) = stress expressed as an integer

<u>Repeat Line 3, NFLIGHT times.</u>

If INVERT = 1, the spectrum is read and the array NSIG is reordered to correspond to the INVERT = 0 option. A new spectrum file is generated named 'spectra9'. FASTRAN-II must then be run using the new spectrum filename.

D. System of Units

All units used for input data must be consistent. For example,

	SI Units	U.S. Customary
Length:	m	in.
Stress:	MPa	ksi
ΔK (or K):	$MPa\text{-}m^{1/2}$	$ksi\text{-}in^{1/2}$
dc/dN (or da/dN):	m/cycle	in/cycle

E. Error Messages

FASTRAN-II has numerous error checks on the input data, some execution errors and many terminating action messages that may be helpful to the user. These error messages are listed and some are briefly discussed.

1. Data Input Errors:

a. ERROR: FINAL LENGTH CF < CI INITIAL CRACK LENGTH
   Value of CF, final crack length, must be greater than the initial crack length, CI.

b. INPUT ERROR: IRATE OR NDKTH
   One or more of the values may be out of bound.

c. INPUT ERROR: NEP OUT OF RANGE--NEP = 'value'
   NEP must be either 0, 1 or 2.

d. ERROR: NOTCH LENGTH CN > CI INITIAL CRACK LENGTH
   Value of CI, initial crack length, must be greater than or equal to notch length, CN.

e. INPUT ERROR: CHECK CRACK-GROWTH RATE TABLE VALUES
   (SIF AND RATES MUST BE IN ASCENDING ORDER)

f. PROOF TEST SIMULATION FOR NTYP=1 (CCT) ONLY

g. THRESHOLD SIMULATION FOR NTYP=1 (CCT) ONLY
   WITH KCONST = LFAST = NFOPT = 0

h. INPUT ERROR: CHECK VALUE OF NRC OR LFAST
   OR SULT MAY BE LESS THAN SYIELD
   Input value of NRC is out of bound or NRC is not -1 for LFAST = 4. Input value of SULT may be less than SYIELD.

i. INPUT ERROR: ALP1 MUST BE GREATER THAN ALP2
   RATE1 MUST BE LESS THAN RATE2

j. INPUT ERROR: NTYP, LFAST, NFOPT, INVERT OR KCONST
   Values are either out of bound or they are not correct for KCONST = 1. For KCONST =1, NTYP must be 1 or 2, NFOPT must be less than or equal to 1 and LFAST = 0.

k. FATIGUE LOADING INPUT ERROR:
   SMIN FOR PREVIOUS CYCLE IS GREATER THAN OR EQUAL TO SMAX
   FOR CURRENT CYCLE NBLK = 'value at error'
   LEVEL = 'value at error'

l. INPUT ERROR: NFOPT = 'value at error'
   Value is out of bound.

m. INPUT ERROR: NALP MUST BE ZERO FOR LFAST=1 OPTION

n. INPUT ERROR: CRACK LENGTH (CI) OR NOTCH LENGTH (CN)
   IS LESS THAN HOLE RADIUS')

o. INPUT ERROR: NTYP = 'value' OR NBCF = 'value'
One or more of the values may be out of bound.

p. LIMITS ON BCF EQUATIONS FOR NTYP = 'value' EXCEEDED

q. INPUT ERROR: NFOPT = 0 AND MAXBLK > 1
Value of MAXBLK must be 1 for NFOPT equal to 0.

r. INPUT ERROR: CHECK LFORMAT
Value is out of bound.

s. INPUT ERROR: CHECK VALUE OF INVERT IN SPECTRUM FILE
Value of INVERT is not correct for spectrum input.

t. CURRENT SMAX LESS THAN OR EQUAL TO PREVIOUS SMIN IN BLOCK 'value' NEAR STRESS POINT 'value'

u. CURRENT SMAX LESS THAN OR EQUAL TO PREVIOUS SMIN IN FLIGHT 'value' NEAR CYCLE 'value'

v. ERROR: NUMBER OF STRESS POINTS EXCEED 2400 IN FLIGHT 'value'
Number of stress points for flight 'value' exceeds 2400. Flight can be divided into smaller flights with less than 2400 stress points per flight.

w. NUMBER OF CYCLES FOR SPECTRUM EXCEEDED (P=5)
Gaussian spectrum can only be repeated five times. Parameter P in Subroutine GAUSS may be set to larger value than 5 but the repetition of the spectrum should be verified.

x. INPUT ERROR: NSQ MUST BE IN ASCENDING ORDER
WITH NSQ(1) EQUAL TO UNITY

2. Execution Errors

a. ERROR: PRIMARY LOADING BEING APPLIED FOR C < CI
Check analysis (input data) file.

b. ERROR: CXO ARRAY OUT OF BOUND NIC = 'value at error'
For crack growth increments (or rates) greater than 1 percent of the crack length, the ΔK_{eff}-rate curve is treated as a "resistance curve" and a iterative technique is used to solve for crack extension values. Maximum number of iterations allowed is 100. Solution could not be found in 100 iterations. This error may also indicate specimen failure.

c. PLASTIC ZONE (RHO) COULD NOT BE FOUND AFTER 100 ITERATIONS IN SUBROUTINE PLZ SMAX = 'value'
Solution for plastic-zone size (ρ) for crack emanating from a hole (NTYP = -4) cannot be found in 100 iterations. Error may be in the applied loading or tensile properties.

d. ITERATIONS EXCEED 100
An iterative method is used to solve for intact and contact stresses in the analytical crack-closure model. Program terminates if a solution cannot be found in 100 iterations.

e. NUMBER OF ELEMENTS EXCEED MAXIMUM ALLOWED '= value'
   Maximum number of elements allowed equals 50.
   Check input data or increase dimension on all
   arrays in COMMON blocks containing 50.

3. Terminating Actions

a. CRACK LENGTH EXCEEDS INPUT VALUE FOR CF
   Set CF = W (width or half-width) to deactivate option.

b. NUMBER OF CYCLES EXCEED 10 MILLION
   Ten million is the limit on cycles that may be applied in a load-reduction test. Limit may be increased by user by changing statement IF(NTC.GT.1.0E+07) GOTO 992.

c. EFFECTIVE STRESS INTENSITY LESS THAN THRESHOLD
   Effective stress-intensity factor range is less than the effective threshold during the Fatigue Precracking stage. Check input values of applied stress or crack lengths.

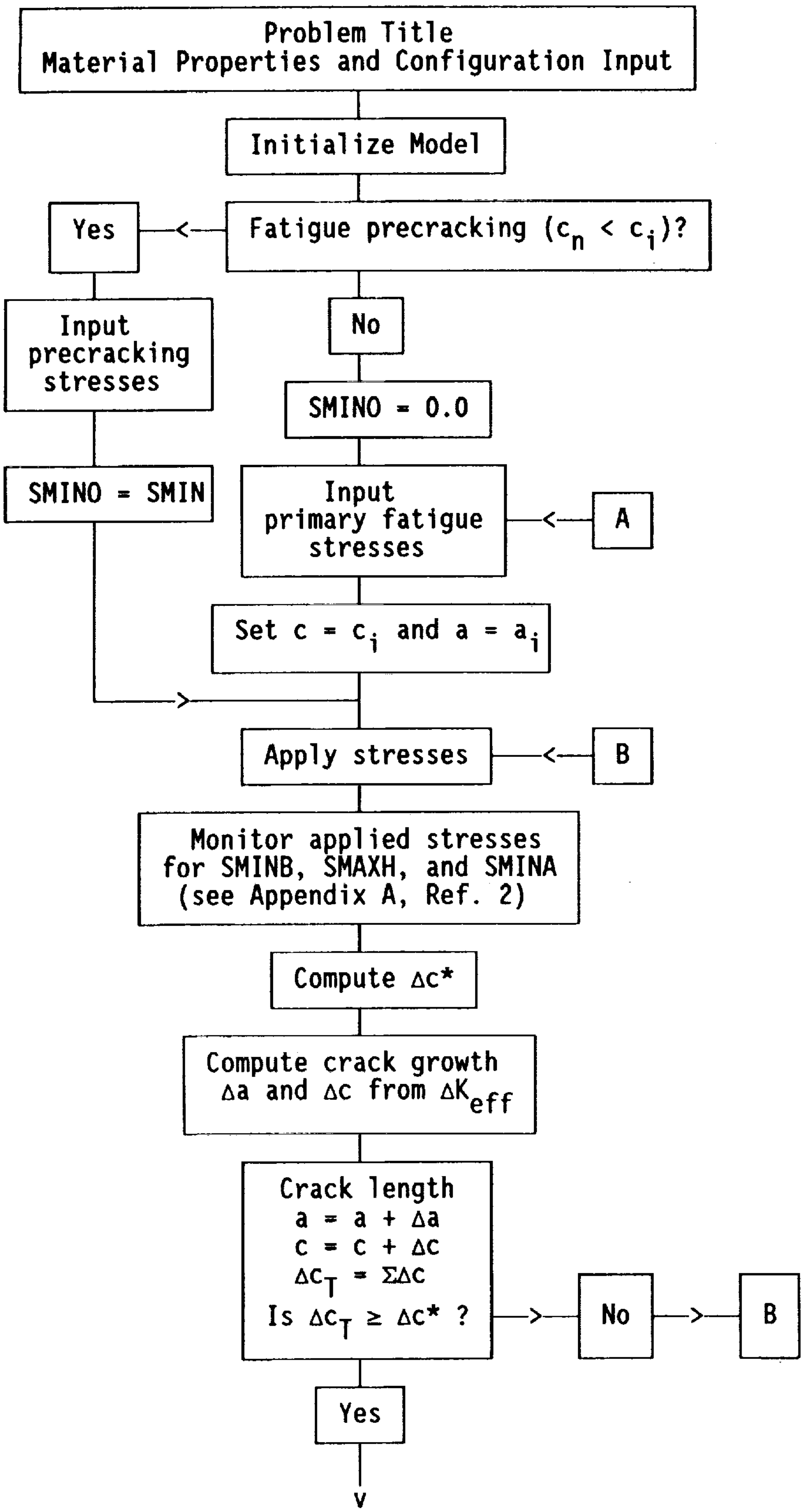
d. NUMBER OF CYCLES EXCEED 10 MILLION:
   SO '= value' MAY BE GREATER THAN SMAX '= value'
   CAUTION: CRACK MAY GROW AROUND OVERLOAD PLASTIC ZONES (IF ANY)
   Number of cycles exceed 10 million during fatigue precracking or the primary fatigue loading stage. For variable-amplitude loading, such as high-to-low block loading, cracks have been shown to grow around overload plastic zones. The current model will try to grow the crack straight through the overload zone which may be physically impossible. This condition may not be prevalent for spectrum loading where peak loads which create the overload zones will be repeated. These peak loads will tend to grow the crack through the overload zone.

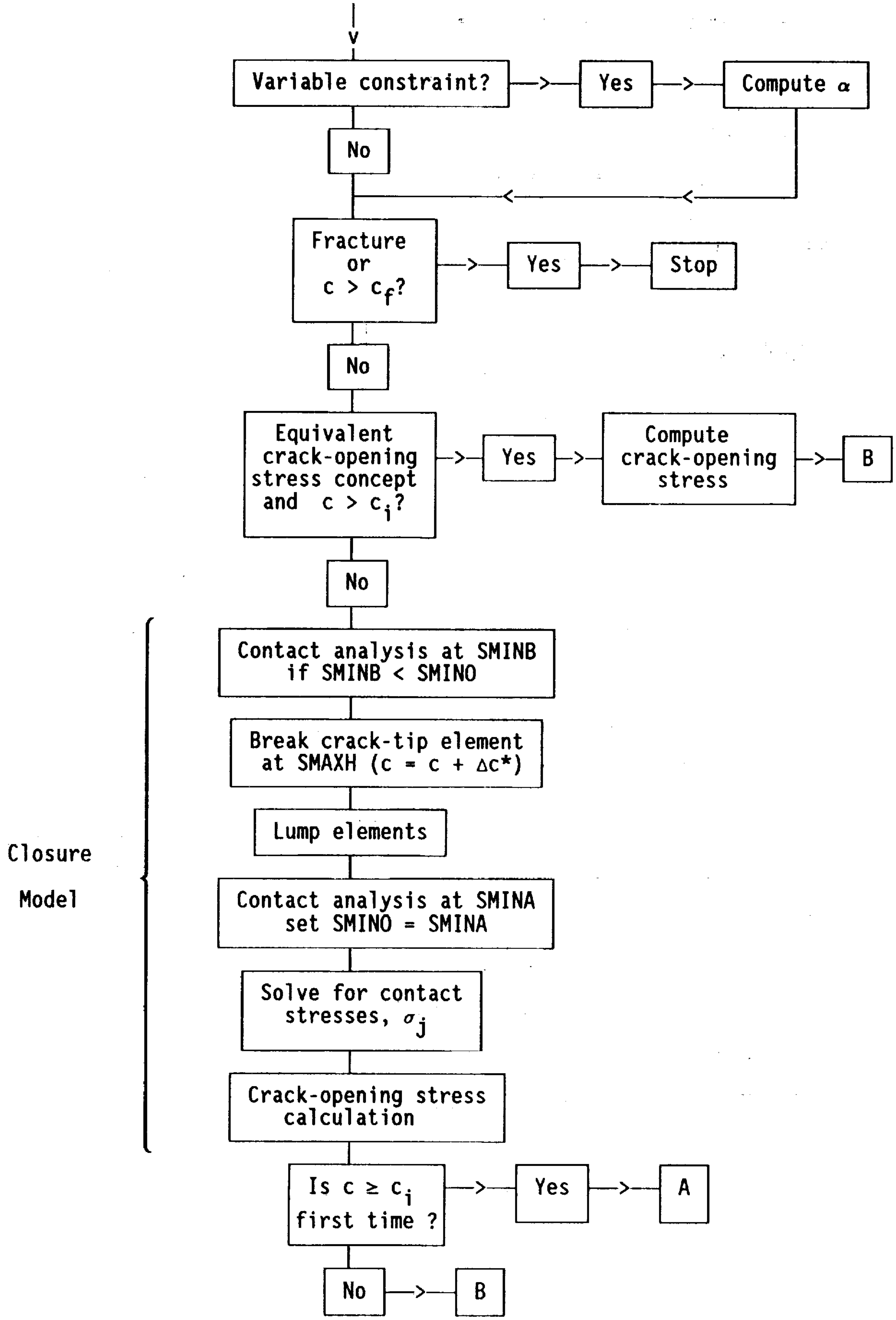
e. BENDING STRESS-INTENSITY FACTOR IS NEGATIVE
   Crack-growth analyses will terminate if the stress-intensity factor range for a surface or corner crack becomes negative.

f. SPECIMEN FAILED DURING PRECRACKING OR C < CI
   PRIMARY FATIGUE LOADING WAS ** NOT ** APPLIED
   If configuration fails or cycles exceed 10 million during fatigue precracking, the primary fatigue loading is printed out but not applied.

g. When a crack configuration fails, the final crack length and number of cycles at failure are printed out. In addition, the terminating action will be also printed. There are seven locations in the program where this terminating action may be initiated. They are identified by the NFCODE. These failure conditions are:
   1. NFCODE = 0: KMAX > C5
   2. NFCODE = 1: CRACK DRIVE > MATERIAL RESISTANCE
   3. NFCODE = 2: KMAX > C5
   4. NFCODE = 3: SMAX > 0.99*SFLOW
   5. NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)
   6. NFCODE = 5: CRACK LENGTH EXCEEDS WIDTH
   7. NFCODE = 6: CRACK LENGTH PLUS PLASTIC ZONE EXCEEDS WIDTH

IV. FASTRAN-II FLOW CHART




Variable constraint?
Yes
Compute α
No
Fracture or c > c_f?
Yes
Stop
No
Equivalent crack-opening stress concept and c > c_i?
Yes
Compute crack-opening stress
B
No
Closure Model
Contact analysis at SMINB if SMINB < SMINO
Break crack-tip element at SMAXH (c = c + Δc*)
Lump elements
Contact analysis at SMINA set SMINO = SMINA
Solve for contact stresses, σ_j
Crack-opening stress calculation
Is c ≥ c_i first time ?
Yes
A
No
B

V. FASTRAN II ANALYSIS FILE--Quick Reference Guide

1. Problem Title

   READ TITLE
   FORMAT (20A4)

2. Spectrum Filename and Time Limit

   READ SPECTRA, TLIMIT
   FORMAT (A10,E10.3)

3. Material

   READ MAT
   FORMAT (20A4)

4. Material Tensile Yielding Properties

   READ SYIELD, SULT, E, ETA, ALP, NALP, NEP, BETA

5. Fatigue-Crack Growth Rate Option

   READ IRATE

   <u>Repeat sections 6 to 7 IRATE times (J = 1 to IRATE).</u>

6. Fatigue-Crack Growth Rate Equation and Fracture Properties

   READ C1(1,J), C2(1,J), C3(J), C4(J), C5(J), KF, M

7. Fatigue-Crack Growth Rate Table (see ref. 5)

   a. READ NTAB, NDKTH

   <u>If NTAB = 0, go to 8, otherwise continue</u>

   b. READ DKETAB(I,J), CGRTAB(I,J)

   <u>Repeat 7b NTAB times.</u>

8. Crack Growth Rates at Transition (<u>NALP = 1 option only</u>)

   READ RATE1, ALP1, BETA1, RATE2, ALP2, BETA2

9. Data Output Options

   READ NIPT, NPRT, LSTEP, NDKE, DCPR

10. Specimen Type and Loading

    READ NTYP, LTYP, LFAST, NS, NFOPT, INVERT, KCONST

11. Specimen and Crack Starter-Notch Dimensions

    READ W, T, CI, AI, CN, AN, HN, RAD

12. Final Crack Length Requested

    READ CF

13. Special Input for Various Crack Configurations

    a. <u>If NTYP = 0 (with LTYP = 2) or NTYP = -10 then:</u>

       READ GAMMA

    b. <u>If NTYP = -7, -8 and -9 then:</u>

       READ XKT, NBCF

    c. <u>If NTYP = 5 then:</u>

       READ RADIUS

14. Input Constant-Amplitude Loading to Initiate Crack from Starter Notch

    READ SMAX, SMIN

15. Special Input for Proof Test or Constant Crack-Opening Stress Concept

    READ NRC, DVALUE

16. Input Primary Fatigue Loading

    a. Constant- or Variable-Amplitude Loading (NFOPT = 0 or 1):

       Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

               LPRINT = MAXLPR = 0

       Line 2: READ SCALE

       Line 3: READ NBLK, NSL(I), NSQ(I)

       Line 4: READ SMAXP(I,J), SMINP(I,J), NCYCP(I,J)

       <u>Repeat lines 3 and 4, MAXBLK times.</u>

    b. TWIST [14] or MINI-TWIST [15] Flight-Load Sequence
       (NFOPT = 2 or 3, respectively):

       Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

               MAXSEQ = 4000   MAXBLK = 10
               LPRINT = 0, 1, or 2

       Line 2: READ SMEAN

    c. FALSTAFF [16] Flight-Load Sequence (NFOPT = 4):

       Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

               MAXSEQ = MAXBLK = 200
               LPRINT = 0, 1, or 2

Line 2: READ SPEAK

d. Space Shuttle Load Sequence (NFOPT = 5):
(SPECTRA = stsn)

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

MAXSEQ = MAXBLK = MAXLPR = 2
LPRINT = 0 or 1

Line 2: READ SPEAK

e. Gaussian Load Sequence [17] (NFOPT = 6):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

MAXSEQ = MAXBLK = 839
LPRINT = 0 or 1

MAXLPR = 4195

Line 2: READ SPEAK, SMEAN

f. Felix/28 [18] Helicopter Load Sequence (NFOPT = 7):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

MAXSEQ = 140 MAXBLK = 12
LPRINT = 0, 1, or 2

Line 2: READ SPEAK

g. Spectrum Read from List of Stress Points (NFOPT = 8):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

MAXSEQ = MAXBLK = (NPOINTS-1)/2400 + 1
LPRINT = 0, 1, or 2

Line 2: READ SPEAK

h. Spectrum Read from Flight-by-Flight Input (NFOPT = 9):

Line 1: READ MAXSEQ, MAXBLK, LPRINT, MAXLPR

MAXSEQ = MAXBLK = NFLIGHTS
LPRINT = 0, 1, or 2

Line 2: READ SPEAK

17. Input Variables for Load-Reduction Threshold Test

READ KTH, SMAXTH, RTH, CONST

VI. EXAMPLE PROBLEMS

A. Introduction

Ten examples problems have been selected to demonstrate the various options in FASTRAN-II. These example problems may be used to verify the operation of the code on other computer systems and to help the user. The material crack-growth rate data in these examples are close to actual properties for most of the materials considered. However, they should only be used as examples and should not be used in damage-tolerance design without verification. For damage-tolerant life calculations, actual crack-growth properties using the crack-closure model analysis should be developed from appropriate tests and analyses on the particular material and crack configurations of interest.

Five computer files are required to run these example problems. They are:

Filename	Description
fastran2.f	Source Code (main and subroutines)
examples	Analysis Input Data Files for Examples
stsn	Spectrum Loading for Space Shuttle (NFOPT = 5)
snfopt8	Sample Spectrum Loading for NFOPT = 8
snfopt9	Sample Spectrum Loading for NFOPT = 9

The analysis (input data) files for the ten examples are listed in Section VI.B. A listing of the output data files are given in Section VI.C. In the following sections, the ten example problems will be briefly described to discuss what options are being tested and to describe the various output data files and options. The ten examples were analyzed during one computer run by placing the ten input data files in series with the word HALT at the end of the last example. The word HALT maybe placed at the end of any other input data file but the computer run will terminate after that example. The total CPU time for all ten examples was 226 seconds on a CONVEX-C210 computer with scalar and vector optimization. The output files for the first few examples will be described in more detail than the other examples.

1. Center-Crack Tension under Constant-Amplitude Loading

The original analytical-crack closure model [2] was developed for a modified Dugdale model of a center-crack tension specimen under plane-stress conditions (constraint factor, $\alpha = 1$). The first example shows results for this specimen made of HT-80 steel under plane-stress conditions. The specimen was fatigue precracked under a different stress level than the primary fatigue loading. The precracking occurred from the saw-cut notch length (CN) to the initial crack length (CI). The initial crack and notch depths were completely through the thickness (AN = AI = T = thickness). A simple power-law was used to express crack-growth rate as a function of effective stress-intensity factor (C1, C2). No threshold stress-intensity factor was used (C3 = C4 = 0.0). Linear-elastic facture mechanics was used to describe the fracture toughness of the material (KF = 80 ksi-$\sqrt{}$in and m = 0.0). The program options output line indicates that the normal closure model was used (LFAST = 0) and contact stress-intensity factors were used to calculate crack opening values (KOPEN = 1 is automatically set in the main program). (Note: A user can change KOPEN in the main program and set KOPEN = 0. This will cause the program to calculate crack-opening values from crack-surface displacement equations [5].) For LSTEP = 2, a detailed output of contact stresses along the crack surface will be given at the minimum applied stress (-10 ksi), at the mean applied stress (10 ksi), and at the maximum applied stress (30 ksi) after every 150 (NIPT) crack-extension increments (Δc^*) in the model. Crack length against cycles results will be printed out after every 0.02 inches (DCPR) of crack extension (NPRT $\le$ 0). Other information given is KO/KMAX (ratio of opening to maximum stress-intensity factor), elastic ΔK (DKC) at crack length c (NDKE = 0) and crack-growth rate (DC/DN). The primary fatigue loading (constant amplitude) was input under NFOPT = 0 option. The primary fatigue loading was applied in blocks of 1000 cycles with a periodic sequence (NSQ) of unity. SCALE was unity, therefore, SMAX and SMIN are as input. When the NIPT option is activated, the contact stresses are printed out. This output shows the number of iterations required to obtain a solution for the contact stresses (usually 10 to 20 iterations), applied stress level and current crack length. (Note: The iterative technique uses the current contact stresses in memory as the initial guess for the new solution. This accounts for the low number of iterations at the minimum applied stress.) The contact-stress output shows element number, element length (residual plastic deformation), crack-opening displacement of elastic body (crack-opening displacement is element LENGTH minus DISPLACEMENT), contact stress along crack surface (element 11 to 23), stresses in plastic zone (elements 1 to 10) and width of element. Element 11 is at the centerline of the crack, elements 11 to 23 are along the crack surface with element 23 (MELE = largest element number) being the element created during the last crack extension and elements 1 to 10 are used to model the plastic zone (see Fig. 1). (MELE is the total number of elements along the crack surface and in the plastic zone.)

Element 1 is at the crack tip and element 10 is at the end of the plastic zone. The current plastic-zone length is also printed out. The specimen failed after 58,026 cycles at a crack length of 1.767. NFCODE = 4 indicates that failure was caused by the maximum stress-intensity factor exceeding the elastic fracture toughness. The CPU time was 2.7 seconds.

2. <u>Through Cracks from Hole under Repeated Spike Loading</u>

The analytical-crack closure model was modified for cracks emanating from a circular hole [5]. This model included the influence of the hole on stress-intensity factors, crack-surface displacements, plastic-zone sizes and crack-opening stresses.

The next example shows results for two symmetric through cracks emanating from a circular hole (NYTP = -4) in a 7075-T651 aluminum alloy plate subjected to repeated spike overloads. A single spike overload was repeated every 5000 cycles after some amount of precracking. A constraint factor of 2 was found from a correlation of constant-amplitude fatigue crack growth rate data (like that shown in refs. 3 and 9). A table look-up procedure was used to relate effective stress intensity factor range (DKEFF) to growth rate using seven data points (NTAB = 7). For ΔK_{eff} values below or above the extreme values given in the table, power-law extrapolations are used using either the first two or last two data points, respectively. Note that crack length in the width direction (c') is measured from the center of the hole and the input of CI, CN and CF must include the physical crack length from the hole plus the hole radius (c + r). (The analysis will terminate if the crack length input is less than the hole radius for NTYP < 0. The code has other input data checks to help protect the user on improper input data, see Error Messages, Section III.E.) A ΔK_{eff}-threshold (C3) of 1 ksi-$\sqrt{in}$ was used for all stress ratios, R (C4 = 0.0). The Two-Parameter Fracture Criterion (TPFC) [12] was used to characterize the fracture behavior of this material (KF = 86.5 ksi-$\sqrt{in}$ and M = 0.7). The output at every 50 (NPRT) analytical crack-growth increments shows the physical crack length (c' - r), the effective stress-intensity factor at crack length c (DKEC) and other information as shown. The KO/KMAX ratio and stress-intensity factors under the primary fatigue loading were based on the highest and lowest levels in the applied sequence. LSTEP = 1 causes detailed contact information to be printed out at the maximum and minimum applied stresses after every 3000 (NIPT) crack-growth increments. Because this configuration was a crack growing from a hole, element 11 (LENGTH = -0.125) automatically became the negative of the radius of the hole. Element

12 simulated a sawcut (h_n= 0.01) that was made at the edge of the hole to act as a crack starter. Elements are automatically placed along any sawcut, such as element 12, because they may come into contact under extreme compressive loading. (NIPT may be set to a very large number, say 9999, to prevent printing of detailed information on contact stresses.) Again, the specimen failed when KMAX was greater than the elastic stress-intensity factor at failure (KIE) computed from the TPFC.

3. <u>Surface-Crack Tension under Constant-Amplitude Loading (LFAST = 1 Option)</u>

The analytical-crack closure model was developed for two-dimensional crack configurations. However, there was a need to calculate damage-tolerant life for three-dimensional crack configurations, such as a surface crack in a plate under tension. To use the model for 3D crack configurations, the crack-opening stress levels computed from the 2D model (under a constraint condition simulating 3D behavior) was assumed to apply at all locations along the surface-crack front. For 3D crack configurations, crack growth was also calculated at two locations: (1) crack length c (or width) direction and (2) the crack depth a (or thickness) direction. Thus, a surface crack may change shape as it grows.

This example shows the application of the model to the growth of a surface crack in 2219-T851 aluminum alloy under constant-amplitude loading for the LFAST = 1 option. Under constant-amplitude loading, the crack-opening stress levels were found to stablize [2] after some amount of crack growth. The LFAST = 1 option causes the program to compute a "damage-weighted average" crack-opening stress (denoted SOBAR). After the crack has grown a predetermined amount (C > CMAX) and if the applied blocks are greater than 2, then the program assumes that the opening stress is constant at SOBAR. At this point, the analytical closure model is turned off and crack-growth calculations are made very rapidly using the SOBAR value and the stress history. The output shows when the "equivalent crack-opening stress" concept is activated. In this example, the equivalent KO/KMAX value of 0.534 was used beyond a crack length of 0.1455. The output shows the stress-intensity factors and crack-growth rates at crack length (c) and at crack depth (a). When the crack depth, a, reaches the plate thickness (a/t = 1), then a through crack of length, c, is assumed in the analysis. The specimen failed when the KMAX value exceeded the maximum stress-intensity factor (C5) in the crack-growth rate equation (eq. 15). The CPU time was less than 1 second whereas the full model (LFAST = 0) would have required 14 seconds. For the LFAST = 1 option, crack-growth lives are usually less than those under LFAST = 0 option. In this case, the life was 6 percent less.

4. Corner Crack from Hole under User Specified Loading

Under variable-amplitude or spectrum loading, the user has the option to define a repeating stress sequence. The user can define up to seven (7) different block (or flight) histories. Each block (or flight) history may have as many as 1200 stress level pairs (1200 values of SMAX; 1200 values of SMIN) in any sequence and each stress level may have any number of cycles. The repeating sequence is based on a periodic sequence number (NSQ) for each block (or flight). This particular option was an early option in FASTRAN and is useful for block (or flight) histories that have a small number of stress levels and those that can be characterized by periodic sequence. If the stress history is extensive, then NFOPT option 8 or 9 should be used.

The fourth example is a corner crack growing from an open hole in a 7075-T651 aluminum alloy plate subjected to a user-defined loading. The user-defined sequence represents a transport-wing spectrum. The spectrum is composed of five (5) different blocks (or flights). Each block is defined with different set of stress levels and cycles. BLOCK 1 has a periodic sequence number (NSQ) of unity and is repeated every time. BLOCK 2 has a periodic sequence number (NSQ) of 5. Thus, every fifth block, such as 5, 15, 25,..., 95 are replaced by BLOCK 2. Every 10th block is replaced by BLOCK 3 (NSQ = 10); the 50th block is replaced by BLOCK 4 (NSQ = 50); and the 100th block is replaced by BLOCK 5 (NSQ = 100). Once the total sequence has been applied, the sequence is repeated until the cracked component fails. Note that SCALE has been used to scale the input spectrum to the desired spectrum stress levels. Here the component failed because the crack length plus plastic zone exceeded the component width.

5. Corner Crack from Hole under Space Shuttle Loading (LFAST = 3 Option)

Example 5 shows an application of the model to predict crack growth under a Space Shuttle load sequence (NFOPT = 5). This option requires that the special file 'stsn' be read in as file SPECTRA. In this example, INVERT was set equal to one which applies the short (reduced) shuttle spectrum. If INVERT = 0, the full shuttle spectrum, composed of 11,430 load reversals, would have been applied. LPRINT was set equal to one so that the reduced spectrum would be printed out. (Note: Using the full shuttle spectrum and LPRINT = 1 will print more information about the spectrum.) The LFAST = 3 option was also used in this case. This option uses the crack-opening stress equations [9], developed for constant-amplitude loading, to calculate a "constant" crack-opening stress using the maximum and minimum applied stress in the total stress sequence. (Caution: This option is extremely fast, low CPU seconds, but the use of this option is only useful for spectra that are repeated quite often, such as short spectra. This option is not recommended for general use and with spectra such as TWIST or FALSTAFF.)

6. Small Crack at Notch under Mini-TWIST Spectrum Loading (NALP = 1 Option)

Example 6 illustrates the growth of small (micro-) cracks at a notch in 7075-T6 aluminum alloy sheet under the Mini-TWIST loading. Two new options are used in this example. First, the crack-growth rate properties in the c and a directions differ. Second, the "variable-constraint" option [11] is also used. In this option, the constraint factor (α) is equal to ALP1 (1.8) for rates lower than RATE1 and is equal to ALP2 (1.2) for rates greater than RATE2. For example, spike overloads applied during the Mini-TWIST sequence may cause a loss of constraint by causing large scale yielding at the crack tip. The baseline constant-amplitude crack-growth rate data must have been analyzed using this same option to obtain the ΔK_{eff} against crack-growth rate relations. A change in constraint has been associated with the transition from flat-to-slant crack growth. Note that for variable-amplitude or spectrum loading the stress-intensity factors (elastic or effective) that are printed out are based on the highest and lowest stresses in the sequence and not on the individual stress values. The crack-growth rates, on the other hand, are rates calculated from individual stress values. Thus, DKC and DC/DN do not correspond. A zero rate is printed out if the effective stress-intensity factor is less than the threshold value (C3 = 1 MPa-$\sqrt{m}$). For surface or corner cracks, DKA and DA/DN have no meaning when A/T becomes unity (the crack becomes a through crack) and values of zero are printed out for these quantities.

7. Compact Specimen under Stress-Intensity Factor Loading

Many laboratory tests are conducted under constant stress-intensity factor loading conditions. This option (KCONST = 1) was also added to FASTRAN-II. However, the current version is restricted to only the center-crack and compact specimens (NTYP = 1 and 2, respectively) tested under the NFOPT options of 0 or 1 (constant and variable amplitude, respectively).

This example shows results for an FVS0812 aluminum alloy compact specimen tested under a repeated spike overload every 100,000 cycles after some precracking at constant stress-intensity factor range. The large number of cycles was selected so that the effects of only a single spike overload could be studied. The precracking and primary fatigue loading is input as K_{max} and K_{min} instead of stress. During primary fatigue loading, the KO/KMAX ratio is based on the "current" maximum stress-intensity factor in the sequence (KMAX = 16.5 or 33 ksi-$\sqrt{in}$). The NALP = 1 option (variable constraint) was also selected. This example shows the loss of constraint during the spike overload, ALP = 1.9 versus 2.17 during constant-amplitude loading. Note that load-interaction effects on constraint have not been considered in FASTRAN-II. In the variable-constraint regime ($2.4 > \alpha > 1.9$), α is computed as if constant-amplitude loading is being applied and, therefore, α is a constant value after the spike overload. (Further study is needed to model load-interaction effects on constraint.) The analysis was terminated when the crack length exceeded the input value of CF.

8. Center-Crack Tension under NFOPT = 8 Option

The next two examples were included to demonstrate the two new methods of inputing spectrum load data. The spectrum loading selected is the first twenty-two flights of the lower-wing structure for a fighter. Example 8 uses the list of stress points (NFOPT = 8) option. The spectrum contains 2,678 stress points with the highest stress point at 723 and the lowest stress point at -99. This option requires that the spectrum be read from a file with INVERT = 0 (stresses are integer numbers input as maximum, minimum, maximum, ..., minimum with a user-selected format). The user-selected format may be either 20I4, 16I5 or 10I8 (LFORMAT = 1, 2 or 3, respectively). If stresses are input with a minimum stress as the first stress point (INVERT = 1), then the program moves the first minimum stress to the end of the spectrum, sets INVERT to zero, creates a new file named 'spectra8' and terminates. The original input spectrum file is not changed or deleted. The user should then re-run FASTRAN-II with the filename 'spectra8'. (There is no limit on the number of stress points. The program reads 2,400 stress points at a time, uses them to grow the crack and returns for another set. Once the total number of stress points in the file has been used, the file is rewound and the process is repeated.) This spectrum was composed of 2 blocks, one block had 2400 stress points and the other had 278 stress points. The maximum desired stress (SPEAK) was input as 35 ksi. Thus, all integer stress points have been scaled by 35/723 and the lowest stress was about -4.79 ksi. In this example, LPRINT was 1 and MAXLPR was 10. Thus, 10 blocks of spectrum information were printed out as the stress history was applied to the specimen. The specimen failed in 25,325 cycles when the maximum applied stress-intensity factor exceeded K_{Ie}, the elastic stress-intensity factor at failure [12].

9. Center-Crack Tension under NFOPT = 9 Option

Example 9 uses the same flight-load history as used in the last example. However, the stresses are read in flight-by-flight sequence. As previously mentioned, the spectra had 22 flights with the highest stress point at 723 and the lowest at -99. Each flight has a flight number and a specified number of stress points in the flight. The flight number, number of stress points and stress values are read in free format. Again, the INVERT options (0 and 1) still apply. If stresses are input with a minimum stress as the first stress point (INVERT = 1), then the program moves the first minimum stress to the end of the spectrum (last stress point in last flight), moves the first minimum stress of the other flights to the end of the preceding flights, sets INVERT to zero, creates a new file named 'spectra9' and terminates. The original input spectrum file is not changed or deleted. The user should then re-run FASTRAN-II with the filename 'spectra9'. In this example, LPRINT was 1 and MAXLPR was 5. Thus, spectrum information was printed out on at least five flights. (Information on seven flights were printed because the program automatically uses seven flights at a time to growth the crack.) The other differences between the output for examples 8 and 9 is that example 9 prints out effective stress-intensity factors (DKEC) instead of elastic stress-intensity factors (DKC), see Section III.B.9 (NDKE), and the crack-length-against-cycles information is printed out in equal crack extension increments (DCPR = 0.04 in.). The specimen failed at the same number of cycles as example 8.

10. Threshold Test (KTH = 3 Option)

The last example is a simulated large-crack threshold test (KTH option). A threshold test is restricted to a center-crPck tension specimen under remote applied stress using the normal closure model (LFAST = 0). There are three types of load-shedding tests that can be simulated. This example uses option KTH = 3 which reduces the applied stress in 10 percent steps after each crack-growth increment of Δc (= CONST). In this example, CONST equals 0.0078 inches. After a precracking stage, the load-shedding procedure is applied. In threshold tests, KO/KMAX and stress-intensity factors are based on the current maximum applied stress and stress ratio. The maximum applied stress is also printed out, in addition to the usual output. Note that with each stress reduction, there is a corresponding rise in the crack-opening stress level and a reduction in the effective stress-intensity factor. The program terminates when the number of cycles exceed 10 million.

B. Listing of Input Data Files for Examples

SAMPLE 1: Center-Crack Tension under Constant-Amplitude Loading

```
cstamp      200.0
  HT-80    STEEL
  115.       119.     30000.     0.0      1.00       0    0    1.0
   1
4.0000E-10  3.00       0.         0.       999.       80.        .0
   0    0
  150    -5    2    0    0.02
   1    0    0    2    0    0    0
  4.0       0.4       0.8       0.4       0.7       0.4       0.0       0.0
  4.0
   25.0      0.0
   0    0.0
   1    1    0    0
    1.0
   1    1    1
   30.0     -10.0           1000
   0      0.0       0.0       0.0
```

SAMPLE 2: Through Cracks from Hole under Repeated Spike Loading

```
cstamp     200.0
  7075-T651
   77.0      85.0    10400.0    0.0       2.0        0    0    1.0
   1
3.2000E-08   2.860      1.0        .0      999.0      86.5       0.7
   7    0
   1.0     3.199E-08
   4.0     1.679E-06
   5.0     5.000E-06
   10.0    2.000E-05
   12.0    3.500E-05
   19.0    2.000E-04
   25.0    1.000E-03
 3000    50    1    1    0.02
  -4    0    0    1    1    0    0
  2.00      0.25      0.145      .25      0.135      .25      0.01      .125
  2.00
   15.0      0.0
   0    0.0
   2    2    0    0
    1.0
   1    1    1
   20.0      0.0              1
   2    1    2
   15.0      0.0            5000
   0      0.0       0.0       0.0
```

SAMPLE 3: Surface-Crack Tension under Constant-Amplitude Loading (LFAST = 1)

```
cstamp     200.0
   2219-T851
    45.0       65.0     10000.0     0.0       1.9        0    0    1.0
    1
1.2000E-07   3.12        2.7        0.8       70.        70.        .0
    0    0
   50    5    1    0    0.02
    0    0    1    1    0    0    0
     4.0     0.3         .136       .030       .136       .030       0.0        0.0
     4.0
    0.0        0.0
    0   0.0
    1    1    0    0
     1.0
    1    1    1
   30.0       15.0           1000
    0       0.0       0.0       0.0
```

SAMPLE 4: Corner Crack from Hole under User Specified Loading

```
cstamp     200.0
   7075-T651
    77.0       85.0     10400.0     0.0       1.0        0    0    1.0
    1
3.2000E-08   3.00        0.         .0      999.0      86.5       0.7
    0    0
 1000   20    1    0    0.02
   -1    0    0    1    1    0    0
   2.00      0.25     0.145       .02       0.145      .02        0.0        .125
   2.00
    0.0        0.0
    0   0.0
  100    5    0    0
    15.00
    1    6       1
    1.2473     0.9000          5
    1.3183     0.8301          2
    1.4007     0.7814          1
    1.3183     0.8301          1
    1.2473     0.9000          4
    1.0000     0.0903          1
    2   10       5
    1.2473     0.9000          5
    1.3183     0.8301          3
    1.4007     0.7814          2
    1.4925     0.6989          1
    1.5806     0.6323          1
    1.4925     0.6989          1
    1.4007     0.7814          1
    1.3183     0.8301          2
    1.2473     0.9000          5
    1.0000     0.0000          1
```

3 11	10		
1.2473	0.9000		5
1.3183	0.8301		3
1.4007	0.7814		2
1.4925	0.6989		2
1.5806	0.6323		1
1.6796	0.5591		1
1.4925	0.6989		1
1.4007	0.7814		1
1.3183	0.8301		2
1.2473	0.9000		5
1.0000	0.0000		1
4 15	50		
1.2473	0.9000		5
1.3183	0.8301		3
1.4007	0.7814		2
1.4925	0.6989		3
1.5806	0.6323		1
1.6796	0.5591		1
1.7742	0.4581		1
1.8796	0.3742		1
1.7742	0.4581		1
1.5806	0.6323		1
1.4925	0.6989		2
1.4007	0.7814		1
1.3183	0.8301		2
1.2473	0.9000		5
1.0000	0.0000		1
5 17	100		
1.2473	0.9000		5
1.3183	0.8301		3
1.4007	0.7814		2
1.4925	0.6989		3
1.5806	0.6323		2
1.6796	0.5591		1
1.7742	0.4581		2
1.8796	0.3742		1
1.9785	0.2581		2
1.7742	0.4581		1
1.6796	0.5591		1
1.5806	0.6323		1
1.4925	0.6989		3
1.4007	0.7814		1
1.3183	0.8301		2
1.2473	0.9000		5
1.0000	0.0000		1
0	0.0	0.0	0.0

SAMPLE 5: Corner Crack at Hole - Space Shuttle Spectrum (LFAST = 3)

```
stsn     200.0
  7075-T7351
 447.00      520.0    71100.       .33       2.50        0     0   1.0
   1
9.9999E-10   4.00       2.50       1.0       999.       80.         0.0
   6    0
  1.0      1.000E-11
  2.0      2.000E-09
  7.0      1.000E-07
 12.0      4.700E-07
 20.0      0.250E-05
 30.0      1.200E-05
 3000   10     1     0   0.001
   -1    0     3     2     5     1     0
 .0350     .014      .013750    .001200  .013750    .001200  0.0      .0075
 .0350
 150.0       -41.4
   0   0.0
   2    2     1     2
 150.00
   0      0.0        0.0        0.0
```

SAMPLE 6: Small Crack at Notch under Mini-TWIST (NALP = 1 Option)

```
cstamp      200.0
  7075-T6
 0.520E+03 0.575E+03 6.960E+04     0.0    0.180E+01    1     0 0.100E+01
   2
 9.999E-11 3.000E+00    0.8      0.0      0.999E+04 0.500E+02 0.000E+00
   7    0
  0.90      1.00E-11
  1.35      1.20E-09
  3.40      1.00E-08
  5.20      1.00E-07
 11.9       1.00E-06
 18.8       1.00E-05
 29.0       1.00E-04
 9.999E-11 3.000E+00    1.0      0.0      0.999E+04 0.500E+02 0.000E+00
   4    0
  0.80      1.00E-11
  1.25      1.00E-09
  3.40      1.00E-08
 14.0       1.00E-06
  0.50E-06   1.8       1.0      0.50E-05   1.2      1.0
 4000   30     1     0   0.01
   -7    0     0     2    3     0     0
 0.0500    0.00115   0.0031840 0.0000025 0.0031840 0.0000025 0.0000025 .003175
 0.05
  3.15        1
  0.0       0.0
   0    0.0
 4000   10     0     0
   90.0
   0      0.0       0.0       0.0
```

SAMPLE 7: Compact Specimen under Stress-Intensity Factor Loading

```
cstamp      200.0
   FVS0812
 0.570E+02 0.660E+02 1.280E+04      0.0    0.240E+01     1     0 0.100E+01
    1
 9.999E-11 3.000E+00     0.0      0.0      0.999E+04 0.400E+02 0.000E+00
    7     0
   0.65       1.00E-09
   0.94       1.00E-08
   1.4        1.00E-07
   3.1        1.00E-06
   7.0        1.00E-05
  11.3        4.40E-05
  22.0        1.00E-03
 4.000E-06    2.4        1.0      6.000E-04   1.90        1.0
 2000     10     1     1     0.02
    2     0      0     1     1     0     1
 2.0          0.250     0.510     0.250      0.48       0.250      0.00       0.0
 0.650
  16.5       1.65
    0   .00
    2     2      0     0
   1.0
    1     1      1
   33.0       3.30                 1
    2     1      2
   16.5       1.65          100000
    0    0.0         0.0         0.0
```

SAMPLE 8: Center-Crack Tension under NFOPT = 8 Option

```
snfopt8     200.0
   2024-T3
    52.0        72.0     10400.       0.0       1.00        0     0    1.0
    1
 2.8700E-09    4.07       0.         0.       999.       400.       1.0
    0     0
  3000     3     1     0     0.04
    1     0     0     1     8     0     0
    12.0        .05       .2         .05        .1         .05        .0        0.0
    12.0
    20.0        2.0
    0    0.0
    2     2     1    10
    35.0
    0        0.0        0.0        0.0
```

```
SAMPLE 9: Center-Crack Tension under NFOPT = 9 Option
snfopt9     200.0
   2024-T3
    52.0       72.0    10400.      0.0      1.00      0    0    1.0
    1
2.8700E-09   4.07       0.         0.       999.      400.      1.0
    0    0
 3000   -20     1    1    0.04
    1    0     0    1    9    0    0
    12.0      .05       .2         .05       .1        .05       .0       0.0
    12.0
    20.0      2.0
    0   0.0
   22   22     1    5
    35.0
    0      0.0      0.0      0.0

SAMPLE 10: Threshold Test (KTH = 3  Option)
cstamp     200.
   2618-T651
    60.0      60.0    10000.      0.0      1.00      0    0    1.0
    1
4.0000E-09   3.50       0.         0.       999.      80.       0.
    0    0
 3000    30     1    0    0.01
    1    0     0    1    0    0    0
  12.0       0.1       0.45      0.1       0.4       0.1       0.0      0.0
   0.70
     7.0      0.7
    0   0.0
    1    1     0    0
     1.0
    1    1     1
     7.0      0.7         1000
    3     7.0      0.1     .0078
HALT
```

C. Listing of Output Data Files for Examples

```
********************************************************************************
*  NASA FATIGUE CRACK GROWTH STRUCTURAL ANALYSIS -- FASTRAN -- CLOSURE MODEL   *
********************************************************************************
         ********  ***       ****  ********  ***      ***    *     **
         *******  *****    ***    ********  *****    *****   **    **
         **      **   **  **         **    **   **  **   **  ***   **
         **      **   **  **         **    **   **  **   **  ****  **
         *****   *******   ***       **    ******   *******  ***** **
         ****    *******     ***     **    *****    *******  ** *****
         **      **   **       **    **    ** **    **   **  **  ****
         **      **   **       **    **    **  **   **   **  **   ***
         **      **   **     ***     **    **   **  **   **  **    **
         **      **   **  ****       **    **    ** **   **  **     *    II
********************************************************************************

SAMPLE 1: Center-Crack Tension under Constant-Amplitude Loading

SPECTRUM FILE = cstamp          TIME LIMIT =  200.0 SECONDS

MATERIAL PROPERTIES:   HT-80   STEEL
YIELD STRESS = 0.1150E+03     ULTIMATE STRENGTH = 0.1190E+03
ELASTIC MODULUS = 0.3000E+05

PLANE STRESS SOLUTION:     CONSTRAINT FACTOR = 0.100E+01
                                        BETA = 0.100E+01

DKEFF IS ELASTIC:
     CRACK GROWTH CONSTANTS:
     C1 =  0.4000E-09   C2 = 3.000   C3 =  0.00   C4 =  0.00   C5 = 0.999E+03
     FRACTURE TOUGHNESS PROPERTIES:    KF = 0.800E+02     M = 0.00

CENTER CRACK TENSION: NTYP = 1
     SPECIMEN WIDTH = 0.400E+01     THICKNESS = 0.400E+00
     INITIAL CRACK LENGTH (CI) = 0.80000E+00   INITIAL CRACK DEPTH = 0.40000E+00
     NOTCH LENGTH (CN) = 0.70000E+00    NOTCH DEPTH = 0.40000E+00
     NOTCH HEIGHT = 0.000E+00    ELEMENTS ON STARTER NOTCH (NS) = 2
     FINAL CRACK LENGTH (CF) REQUESTED =  0.40000E+01

PROGRAM OPTIONS:  LFAST = 0   KOPEN = 1   KCONST = 0   INVERT = 0   LSTEP = 2
  ERR = 0.234E+01  PDC = 0.20  NMAX =1000  NIPT =  150  NPRT = -5  NDKE = 0
  DCPR = 0.200E-01

  PRECRACKING FROM STARTER NOTCH:
  MAX STRESS = 0.2500E+02     MIN STRESS =  0.0000E+00
```

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
0	0.7200E+00	1.0000	2299	1.00	0.384	38.37	0.528E-05	0.00	0.000E+00
0	0.7400E+00	1.0000	6826	1.00	0.450	38.94	0.392E-05	0.00	0.000E+00
0	0.7600E+00	1.0000	12258	1.00	0.475	39.51	0.357E-05	0.00	0.000E+00
0	0.7800E+00	1.0000	17929	1.00	0.485	40.07	0.351E-05	0.00	0.000E+00
0	0.8000E+00	1.0000	24237	1.00	0.490	40.64	0.357E-05	0.00	0.000E+00

BLOCK (OR FLIGHT) LOADING: NFOPT = 0 LPRINT = 0 MAXLPR = 0
TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED = 1
NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) = 1

BLOCK 1 NUMBER OF STRESS LEVELS = 1 NSQ = 1 SCALE = 1.00

LEVEL	SMAX	SMIN	CYCLES
1	0.3000E+02	-0.1000E+02	1000

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
2	0.8200E+00	1.0000	1545	1.00	0.352	65.91	0.131E-04	0.00	0.000E+00
4	0.8400E+00	1.0000	3240	1.00	0.398	66.80	0.109E-04	0.00	0.000E+00
5	0.8600E+00	1.0000	5160	1.00	0.421	67.68	0.101E-04	0.00	0.000E+00
7	0.8800E+00	1.0000	7157	1.00	0.433	68.55	0.992E-05	0.00	0.000E+00
10	0.9000E+00	1.0000	9181	1.00	0.440	69.43	0.990E-05	0.00	0.000E+00
12	0.9200E+00	1.0000	11200	1.00	0.446	70.31	0.100E-04	0.00	0.000E+00
13	0.9400E+00	1.0000	13172	1.00	0.447	71.16	0.102E-04	0.00	0.000E+00
16	0.9600E+00	1.0000	15096	1.00	0.451	72.04	0.105E-04	0.00	0.000E+00
17	0.9800E+00	1.0000	16969	1.00	0.450	72.89	0.109E-04	0.00	0.000E+00
19	0.1000E+01	1.0000	18795	1.00	0.451	73.74	0.111E-04	0.00	0.000E+00
21	0.1020E+01	1.0000	20560	1.00	0.452	74.59	0.115E-04	0.00	0.000E+00
22	0.1040E+01	1.0000	22273	1.00	0.453	75.44	0.118E-04	0.00	0.000E+00
24	0.1060E+01	1.0000	23930	1.00	0.453	76.29	0.123E-04	0.00	0.000E+00
26	0.1080E+01	1.0000	25539	1.00	0.453	77.15	0.126E-04	0.00	0.000E+00
27	0.1100E+01	1.0000	27087	1.00	0.452	78.00	0.131E-04	0.00	0.000E+00
29	0.1120E+01	1.0000	28586	1.00	0.452	78.87	0.137E-04	0.00	0.000E+00
30	0.1140E+01	1.0000	30037	1.00	0.453	79.69	0.139E-04	0.00	0.000E+00
32	0.1160E+01	1.0000	31443	1.00	0.454	80.56	0.144E-04	0.00	0.000E+00
33	0.1180E+01	1.0000	32806	1.00	0.453	81.38	0.149E-04	0.00	0.000E+00
34	0.1200E+01	1.0000	34113	1.00	0.450	82.26	0.157E-04	0.00	0.000E+00
36	0.1220E+01	1.0000	35373	1.00	0.450	83.09	0.161E-04	0.00	0.000E+00
37	0.1240E+01	1.0000	36612	1.00	0.452	83.93	0.164E-04	0.00	0.000E+00
38	0.1260E+01	1.0000	37805	1.00	0.451	84.82	0.171E-04	0.00	0.000E+00
39	0.1280E+01	1.0000	38957	1.00	0.450	85.67	0.177E-04	0.00	0.000E+00
40	0.1300E+01	1.0000	40075	1.00	0.450	86.52	0.182E-04	0.00	0.000E+00
42	0.1320E+01	1.0000	41156	1.00	0.449	87.38	0.189E-04	0.00	0.000E+00
43	0.1340E+01	1.0000	42201	1.00	0.448	88.24	0.195E-04	0.00	0.000E+00
44	0.1360E+01	1.0000	43214	1.00	0.449	89.11	0.200E-04	0.00	0.000E+00
44	0.1380E+01	1.0000	44198	1.00	0.448	89.91	0.205E-04	0.00	0.000E+00
45	0.1400E+01	1.0000	45146	1.00	0.446	90.79	0.214E-04	0.00	0.000E+00
46	0.1420E+01	1.0000	46064	1.00	0.446	91.68	0.222E-04	0.00	0.000E+00
47	0.1440E+01	1.0000	46953	1.00	0.445	92.58	0.229E-04	0.00	0.000E+00
48	0.1460E+01	1.0000	47815	1.00	0.444	93.40	0.236E-04	0.00	0.000E+00
49	0.1480E+01	1.0000	48648	1.00	0.444	94.32	0.245E-04	0.00	0.000E+00
50	0.1500E+01	1.0000	49455	1.00	0.443	95.15	0.251E-04	0.00	0.000E+00
51	0.1520E+01	1.0000	50230	1.00	0.440	96.09	0.264E-04	0.00	0.000E+00
51	0.1540E+01	1.0000	50981	1.00	0.440	96.93	0.269E-04	0.00	0.000E+00
52	0.1560E+01	1.0000	51708	1.00	0.438	97.90	0.282E-04	0.00	0.000E+00
53	0.1580E+01	1.0000	52410	1.00	0.438	98.76	0.289E-04	0.00	0.000E+00
53	0.1600E+01	1.0000	53092	1.00	0.437	99.63	0.298E-04	0.00	0.000E+00
54	0.1620E+01	1.0000	53758	1.00	0.439	100.50	0.302E-04	0.00	0.000E+00
55	0.1640E+01	1.0000	54403	1.00	0.437	101.53	0.317E-04	0.00	0.000E+00
55	0.1660E+01	1.0000	55025	1.00	0.435	102.43	0.329E-04	0.00	0.000E+00

CONVERGENCE IN 2 ITERATIONS

APPLIED STRESS = -0.1000E+02 CRACK LENGTH = 0.16772E+01

ELEMENT	LENGTH	DISPLACEMENT	STRESS	WIDTH	
11	0.00000E+00	-0.64029E-06	-6.561	0.35000E+00	CENTER-LINE
12	0.00000E+00	0.80951E-06	-1.116	0.35000E+00	
13	0.21583E-03	0.21668E-03	-12.165	0.14949E+00	
14	0.39472E-03	0.39549E-03	-15.361	0.37225E+00	
15	0.53862E-03	0.53921E-03	-19.142	0.21732E+00	
16	0.62370E-03	0.62323E-03	-26.981	0.95395E-01	
17	0.66698E-03	0.66558E-03	-34.556	0.51257E-01	
18	0.69641E-03	0.69528E-03	-43.739	0.44736E-01	
19	0.71348E-03	0.71313E-03	-53.454	0.91738E-02	
20	0.71947E-03	0.71988E-03	-65.637	0.92688E-02	
21	0.72559E-03	0.72568E-03	-67.708	0.93569E-02	
22	0.73176E-03	0.73186E-03	-79.308	0.94185E-02	
23	0.73805E-03	0.73795E-03	-117.000	0.95153E-02	CRACK TIP
1	0.72764E-03	0.72786E-03	-115.208	0.19176E-02	
2	0.72276E-03	0.72289E-03	-116.272	0.19176E-02	
3	0.71441E-03	0.71457E-03	-116.526	0.38352E-02	
4	0.69072E-03	0.69097E-03	-116.592	0.76704E-02	
5	0.62833E-03	0.62862E-03	-86.809	0.11506E-01	
6	0.51392E-03	0.51396E-03	-29.664	0.17258E-01	
7	0.38240E-03	0.38246E-03	-4.222	0.23011E-01	
8	0.24910E-03	0.24914E-03	11.134	0.28764E-01	
9	0.11944E-03	0.11946E-03	22.406	0.38352E-01	
10	0.72254E-05	0.72443E-05	32.066	0.57528E-01	

PLASTIC ZONE = 0.1918E+00 END OF PLASTIC ZONE

CONVERGENCE IN 19 ITERATIONS

APPLIED STRESS = 0.1000E+02 CRACK LENGTH = 0.16772E+01

ELEMENT	LENGTH	DISPLACEMENT	STRESS	WIDTH	
11	0.00000E+00	0.14191E-02	0.000	0.35000E+00	CENTER-LINE
12	0.00000E+00	0.13667E-02	0.000	0.35000E+00	
13	0.21583E-03	0.12941E-02	0.000	0.14949E+00	
14	0.39472E-03	0.11807E-02	0.000	0.37225E+00	
15	0.53862E-03	0.99137E-03	0.000	0.21732E+00	
16	0.62370E-03	0.85420E-03	0.000	0.95395E-01	
17	0.66698E-03	0.78040E-03	0.000	0.51257E-01	
18	0.69641E-03	0.73387E-03	0.000	0.44736E-01	
19	0.71348E-03	0.71752E-03	0.000	0.91738E-02	
20	0.71947E-03	0.71997E-03	-8.490	0.92688E-02	
21	0.72559E-03	0.72620E-03	-23.569	0.93569E-02	
22	0.73176E-03	0.73207E-03	-38.176	0.94185E-02	
23	0.73795E-03	0.73779E-03	-78.008	0.95153E-02	CRACK TIP
1	0.72764E-03	0.72689E-03	-76.020	0.19176E-02	
2	0.72276E-03	0.72237E-03	-74.342	0.19176E-02	
3	0.71441E-03	0.71438E-03	-77.326	0.38352E-02	
4	0.69072E-03	0.69071E-03	-78.311	0.76704E-02	
5	0.62833E-03	0.62834E-03	-49.568	0.11506E-01	
6	0.51392E-03	0.51393E-03	6.141	0.17258E-01	
7	0.38240E-03	0.38241E-03	30.025	0.23011E-01	
8	0.24910E-03	0.24911E-03	44.350	0.28764E-01	
9	0.11944E-03	0.11945E-03	54.576	0.38352E-01	
10	0.72254E-05	0.72321E-05	63.150	0.57528E-01	

PLASTIC ZONE = 0.1918E+00 END OF PLASTIC ZONE

CONVERGENCE IN 2 ITERATIONS

APPLIED STRESS = 0.3000E+02   CRACK LENGTH = 0.16772E+01

ELEMENT	LENGTH	DISPLACEMENT	STRESS	WIDTH	
11	0.00000E+00	0.40000E-02	0.000	0.35000E+00	CENTER-LINE
12	0.00000E+00	0.38313E-02	0.000	0.35000E+00	
13	0.21583E-03	0.35956E-02	0.000	0.14949E+00	
14	0.39472E-03	0.32218E-02	0.000	0.37225E+00	
15	0.53862E-03	0.25713E-02	0.000	0.21732E+00	
16	0.62370E-03	0.20546E-02	0.000	0.95395E-01	
17	0.66698E-03	0.17317E-02	0.000	0.51257E-01	
18	0.69641E-03	0.14680E-02	0.000	0.44736E-01	
19	0.71348E-03	0.12878E-02	0.000	0.91738E-02	
20	0.71947E-03	0.12176E-02	0.000	0.92688E-02	
21	0.72559E-03	0.11400E-02	0.000	0.93569E-02	
22	0.73176E-03	0.10522E-02	0.000	0.94185E-02	
23	0.73795E-03	0.94598E-03	0.000	0.95153E-02	CRACK
1	0.72764E-03	0.85312E-03	117.000	0.19176E-02	TIP
2	0.72276E-03	0.82353E-03	117.000	0.19176E-02	
3	0.71441E-03	0.78518E-03	117.000	0.38352E-02	
4	0.69072E-03	0.71995E-03	117.000	0.76704E-02	
5	0.62833E-03	0.62833E-03	117.000	0.11506E-01	
6	0.51392E-03	0.51392E-03	117.000	0.17258E-01	
7	0.38240E-03	0.38240E-03	117.000	0.23011E-01	
8	0.24910E-03	0.24910E-03	117.000	0.28764E-01	
9	0.11944E-03	0.11944E-03	117.000	0.38352E-01	
10	0.72254E-05	0.72254E-05	117.000	0.57528E-01	

PLASTIC ZONE = 0.1918E+00   END OF PLASTIC ZONE

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
56	0.1680E+01	1.0000	55626	1.00	0.434	103.34	0.339E-04	0.00	0.000E+00
57	0.1700E+01	1.0000	56209	1.00	0.433	104.26	0.350E-04	0.00	0.000E+00
57	0.1720E+01	1.0000	56772	1.00	0.431	105.19	0.362E-04	0.00	0.000E+00
58	0.1740E+01	1.0000	57317	1.00	0.431	106.13	0.373E-04	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 1.7670   CRACK DEPTH = 0.4000   TOTAL CYCLES = 58026

NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)

CPU TIME = 2.7 SECONDS

****

SAMPLE 2: Through Cracks from Hole under Repeated Spike Loading

SPECTRUM FILE = cstamp   TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: 7075-T651
YIELD STRESS = 0.7700E+02   ULTIMATE STRENGTH = 0.8500E+02
ELASTIC MODULUS = 0.1040E+05

PLANE STRESS SOLUTION: CONSTRAINT FACTOR = 0.200E+01
BETA = 0.100E+01

```
DKEFF IS ELASTIC:
    CRACK GROWTH RATES FROM TABLE LOOKUP (NDKTH = 0):
              DKEFF            RATE
           0.1000E+01       0.3199E-07
           0.4000E+01       0.1679E-05
           0.5000E+01       0.5000E-05
           0.1000E+02       0.2000E-04
           0.1200E+02       0.3500E-04
           0.1900E+02       0.2000E-03
           0.2500E+02       0.1000E-02

    THRESHOLD CONSTANTS:   C3 =  1.00      C4 =  0.00

    FRACTURE TOUGHNESS PROPERTIES:     KF = 0.865E+02      M = 0.70


TWO SYMMETRIC THROUGH CRACKS AT HOLE: NTYP = -4
    SPECIMEN WIDTH = 0.200E+01      THICKNESS = 0.250E+00
    INITIAL CRACK LENGTH (CI) = 0.14500E+00   INITIAL CRACK DEPTH = 0.25000E+00
    NOTCH LENGTH (CN) = 0.13500E+00    NOTCH DEPTH = 0.25000E+00
    NOTCH HEIGHT = 0.100E-01    ELEMENTS ON STARTER NOTCH (NS) = 2
    FINAL CRACK LENGTH (CF) REQUESTED =  0.20000E+01
    HOLE RADIUS (RAD) =  0.12500E+00

PROGRAM OPTIONS:  LFAST = 0   KOPEN = 1   KCONST = 0   INVERT = 0   LSTEP = 1
  ERR = 0.162E+01  PDC = 0.20  NMAX =1000  NIPT = 3000  NPRT = 50  NDKE = 1

  PRECRACKING FROM STARTER NOTCH:
  MAX STRESS = 0.1500E+02      MIN STRESS =  0.0000E+00

 BLOCK    C`-RAD      A/T   CYCLES  ALP  KO/KMAX  DKEC  DC/DN      DKEA  DA/DN

    0  0.1270E-01 1.0000     388  2.00  0.315    5.73 0.657E-05   0.00 0.000E+00
    0  0.1580E-01 1.0000     838  2.00  0.329    6.02 0.725E-05   0.00 0.000E+00
    0  0.1924E-01 1.0000    1288  2.00  0.335    6.33 0.802E-05   0.00 0.000E+00

  BLOCK (OR FLIGHT) LOADING:  NFOPT = 1     LPRINT = 0      MAXLPR =     0
     TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED =    2
     NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) =    2

    BLOCK  1     NUMBER OF STRESS LEVELS =    1    NSQ =    1    SCALE =    1.00
               LEVEL      SMAX             SMIN            CYCLES
                 1     0.2000E+02      0.0000E+00               1

    BLOCK  2     NUMBER OF STRESS LEVELS =    1    NSQ =    2    SCALE =    1.00
               LEVEL      SMAX             SMIN            CYCLES
                 1     0.1500E+02      0.0000E+00            5000

  NOTE: KO/KMAX AND SIF BASED ON HIGHEST AND LOWEST APPLIED STRESS IN SEQUENCE

 BLOCK    C`-RAD      A/T   CYCLES  ALP  KO/KMAX  DKEC  DC/DN      DKEA  DA/DN

    2  0.2013E-01 1.0000      16  2.00  0.270    6.16 0.760E-05   0.00 0.000E+00
    2  0.2405E-01 1.0000     505  2.00  0.258    6.63 0.878E-05   0.00 0.000E+00
    2  0.2819E-01 1.0000     955  2.00  0.256    6.91 0.955E-05   0.00 0.000E+00
    2  0.3263E-01 1.0000    1405  2.00  0.257    7.13 0.102E-04   0.00 0.000E+00
    2  0.3732E-01 1.0000    1855  2.00  0.258    7.31 0.107E-04   0.00 0.000E+00
    2  0.4224E-01 1.0000    2305  2.00  0.260    7.47 0.112E-04   0.00 0.000E+00
```

2	0.4737E-01	1.0000	2755	2.00	0.260	7.62	0.116E-04	0.00	0.000E+00
2	0.5269E-01	1.0000	3205	2.00	0.261	7.76	0.120E-04	0.00	0.000E+00
2	0.5820E-01	1.0000	3655	2.00	0.261	7.90	0.125E-04	0.00	0.000E+00
2	0.6390E-01	1.0000	4105	2.00	0.261	8.02	0.129E-04	0.00	0.000E+00
2	0.6976E-01	1.0000	4555	2.00	0.262	8.14	0.132E-04	0.00	0.000E+00
4	0.7591E-01	1.0000	5010	2.00	0.262	8.25	0.136E-04	0.00	0.000E+00
4	0.8247E-01	1.0000	5521	2.00	0.266	8.31	0.138E-04	0.00	0.000E+00
4	0.8903E-01	1.0000	5987	2.00	0.264	8.46	0.143E-04	0.00	0.000E+00
4	0.9559E-01	1.0000	6437	2.00	0.263	8.60	0.148E-04	0.00	0.000E+00
4	0.1023E+00	1.0000	6887	2.00	0.263	8.72	0.152E-04	0.00	0.000E+00
4	0.1093E+00	1.0000	7337	2.00	0.263	8.84	0.156E-04	0.00	0.000E+00
4	0.1164E+00	1.0000	7787	2.00	0.263	8.95	0.160E-04	0.00	0.000E+00
4	0.1237E+00	1.0000	8237	2.00	0.263	9.07	0.165E-04	0.00	0.000E+00
4	0.1312E+00	1.0000	8687	2.00	0.264	9.18	0.169E-04	0.00	0.000E+00
4	0.1389E+00	1.0000	9137	2.00	0.264	9.31	0.173E-04	0.00	0.000E+00
4	0.1468E+00	1.0000	9587	2.00	0.263	9.45	0.178E-04	0.00	0.000E+00
6	0.1551E+00	1.0000	10035	2.00	0.223	10.36	0.223E-04	0.00	0.000E+00
6	0.1640E+00	1.0000	10547	2.00	0.269	9.60	0.184E-04	0.00	0.000E+00
6	0.1726E+00	1.0000	11003	2.00	0.264	9.83	0.193E-04	0.00	0.000E+00
6	0.1814E+00	1.0000	11453	2.00	0.263	9.98	0.199E-04	0.00	0.000E+00
6	0.1906E+00	1.0000	11903	2.00	0.264	10.11	0.207E-04	0.00	0.000E+00
6	0.2001E+00	1.0000	12353	2.00	0.263	10.27	0.217E-04	0.00	0.000E+00
6	0.2101E+00	1.0000	12803	2.00	0.264	10.40	0.226E-04	0.00	0.000E+00
6	0.2206E+00	1.0000	13253	2.00	0.263	10.59	0.238E-04	0.00	0.000E+00
6	0.2315E+00	1.0000	13703	2.00	0.264	10.73	0.248E-04	0.00	0.000E+00
6	0.2430E+00	1.0000	14153	2.00	0.263	10.91	0.261E-04	0.00	0.000E+00
6	0.2544E+00	1.0000	14583	2.00	0.262	11.10	0.276E-04	0.00	0.000E+00
6	0.2657E+00	1.0000	14988	2.00	0.264	11.23	0.286E-04	0.00	0.000E+00
8	0.2779E+00	1.0000	15447	2.00	0.270	11.27	0.288E-04	0.00	0.000E+00
8	0.2900E+00	1.0000	15847	2.00	0.265	11.55	0.311E-04	0.00	0.000E+00
8	0.3028E+00	1.0000	16247	2.00	0.264	11.75	0.328E-04	0.00	0.000E+00
8	0.3163E+00	1.0000	16647	2.00	0.264	11.96	0.346E-04	0.00	0.000E+00
8	0.3306E+00	1.0000	17047	2.00	0.264	12.15	0.367E-04	0.00	0.000E+00
8	0.3449E+00	1.0000	17426	2.00	0.266	12.32	0.386E-04	0.00	0.000E+00
8	0.3590E+00	1.0000	17776	2.00	0.264	12.55	0.415E-04	0.00	0.000E+00
8	0.3739E+00	1.0000	18126	2.00	0.264	12.77	0.443E-04	0.00	0.000E+00
8	0.3899E+00	1.0000	18476	2.00	0.265	12.98	0.471E-04	0.00	0.000E+00
8	0.4070E+00	1.0000	18826	2.00	0.265	13.22	0.505E-04	0.00	0.000E+00
8	0.4242E+00	1.0000	19156	2.00	0.267	13.40	0.532E-04	0.00	0.000E+00
8	0.4408E+00	1.0000	19456	2.00	0.265	13.67	0.574E-04	0.00	0.000E+00
8	0.4587E+00	1.0000	19756	2.00	0.265	13.93	0.617E-04	0.00	0.000E+00
10	0.4781E+00	1.0000	20051	2.00	0.302	13.14	0.494E-04	0.00	0.000E+00
10	0.4977E+00	1.0000	20382	2.00	0.268	14.41	0.700E-04	0.00	0.000E+00
10	0.5191E+00	1.0000	20674	2.00	0.264	14.82	0.779E-04	0.00	0.000E+00
10	0.5395E+00	1.0000	20932	2.00	0.267	15.03	0.822E-04	0.00	0.000E+00
10	0.5609E+00	1.0000	21182	2.00	0.267	15.34	0.888E-04	0.00	0.000E+00
10	0.5842E+00	1.0000	21432	2.00	0.267	15.68	0.966E-04	0.00	0.000E+00
10	0.6094E+00	1.0000	21682	2.00	0.266	16.06	0.106E-03	0.00	0.000E+00
10	0.6370E+00	1.0000	21931	2.00	0.273	16.26	0.111E-03	0.00	0.000E+00
10	0.6629E+00	1.0000	22147	2.00	0.268	16.80	0.125E-03	0.00	0.000E+00
10	0.6892E+00	1.0000	22347	2.00	0.268	17.20	0.137E-03	0.00	0.000E+00
10	0.7182E+00	1.0000	22547	2.00	0.267	17.67	0.152E-03	0.00	0.000E+00
10	0.7502E+00	1.0000	22747	2.00	0.268	18.17	0.169E-03	0.00	0.000E+00
10	0.7861E+00	1.0000	22947	2.00	0.268	18.75	0.190E-03	0.00	0.000E+00

CONVERGENCE IN 2 ITERATIONS
APPLIED STRESS = 0.1500E+02 CRACK LENGTH = 0.94685E+00

ELEMENT	LENGTH	DISPLACEMENT	STRESS	WIDTH	CENTER-
11	-0.12500E+00	0.32001E-02	0.000	0.12500E+00	LINE
12	-0.10000E-01	0.31769E-02	0.000	0.10000E-01	
13	0.24429E-04	0.31587E-02	0.000	0.58931E-01	
14	0.47516E-04	0.30420E-02	0.000	0.21447E+00	
15	0.82233E-04	0.26859E-02	0.000	0.22244E+00	
16	0.11551E-03	0.21697E-02	0.000	0.13894E+00	
17	0.13841E-03	0.17011E-02	0.000	0.72762E-01	
18	0.15296E-03	0.13446E-02	0.000	0.41574E-01	
19	0.16238E-03	0.10625E-02	0.000	0.26205E-01	
20	0.16879E-03	0.82044E-03	0.000	0.17840E-01	
21	0.17184E-03	0.63324E-03	0.000	0.78680E-02	
22	0.17351E-03	0.51855E-03	0.000	0.43891E-02	
23	0.17460E-03	0.43337E-03	0.000	0.29872E-02	
24	0.17498E-03	0.38271E-03	0.000	0.67788E-03	
25	0.17553E-03	0.35922E-03	0.000	0.82884E-03	
26	0.17545E-03	0.33328E-03	0.000	0.68413E-03	
27	0.17532E-03	0.30791E-03	0.000	0.62813E-03	
28	0.17535E-03	0.27901E-03	0.000	0.62782E-03	CRACK
1	0.17389E-03	0.25437E-03	162.000	0.12513E-03	TIP
2	0.17327E-03	0.24655E-03	162.000	0.12513E-03	
3	0.17225E-03	0.23634E-03	162.000	0.25026E-03	
4	0.16969E-03	0.21881E-03	162.000	0.50053E-03	
5	0.16409E-03	0.19389E-03	162.000	0.75079E-03	
6	0.15203E-03	0.16231E-03	162.000	0.11262E-02	
7	0.12529E-03	0.12529E-03	162.000	0.15016E-02	
8	0.86756E-04	0.86756E-04	162.000	0.18770E-02	
9	0.47740E-04	0.47740E-04	162.000	0.25026E-02	
10	0.10388E-04	0.10388E-04	162.000	0.37539E-02	

PLASTIC ZONE = 0.1251E-01 END OF PLASTIC ZONE

CONVERGENCE IN 11 ITERATIONS
APPLIED STRESS = 0.0000E+00 CRACK LENGTH = 0.94749E+00

ELEMENT	LENGTH	DISPLACEMENT	STRESS	WIDTH	CENTER-
11	-0.12500E+00	0.65898E-04	0.000	0.12500E+00	LINE
12	-0.10000E-01	0.66479E-04	0.000	0.10000E-01	
13	0.24429E-04	0.66945E-04	0.000	0.58931E-01	
14	0.47516E-04	0.70125E-04	0.000	0.21447E+00	
15	0.82233E-04	0.82714E-04	0.000	0.22244E+00	
16	0.11551E-03	0.11538E-03	-0.929	0.13894E+00	
17	0.13841E-03	0.13806E-03	-1.950	0.72762E-01	
18	0.15296E-03	0.15251E-03	-3.442	0.41574E-01	
19	0.16238E-03	0.16207E-03	-5.647	0.26205E-01	
20	0.16879E-03	0.16884E-03	-9.475	0.17840E-01	
21	0.17184E-03	0.17227E-03	-14.805	0.78680E-02	
22	0.17351E-03	0.17411E-03	-21.423	0.43891E-02	
23	0.17467E-03	0.17496E-03	-30.375	0.36651E-02	
24	0.17553E-03	0.17542E-03	-43.874	0.82884E-03	
25	0.17545E-03	0.17508E-03	-48.356	0.68413E-03	
26	0.17532E-03	0.17517E-03	-48.520	0.62813E-03	
27	0.17535E-03	0.17537E-03	-57.221	0.62782E-03	
28	0.25437E-03	0.17544E-03	-81.000	0.63537E-03	CRACK
1	0.25464E-03	0.17399E-03	-81.000	0.12526E-03	TIP
2	0.24681E-03	0.17336E-03	-81.000	0.12526E-03	
3	0.23659E-03	0.17235E-03	-81.000	0.25051E-03	
4	0.21904E-03	0.16980E-03	-81.000	0.50103E-03	

5	0.19410E-03	0.16421E-03	-81.000	0.75154E-03
6	0.16248E-03	0.15216E-03	-81.000	0.11273E-02
7	0.12543E-03	0.12537E-03	-40.361	0.15031E-02
8	0.86848E-04	0.86813E-04	14.134	0.18789E-02
9	0.47790E-04	0.47784E-04	38.998	0.25051E-02
10	0.10399E-04	0.10395E-04	59.202	0.37577E-02

PLASTIC ZONE = 0.1253E-01 END OF PLASTIC ZONE

BLOCK	C'-RAD	A/T	CYCLES	ALP	KO/KMAX	DKEC	DC/DN	DKEA	DA/DN
10	0.8231E+00	1.0000	23130	2.00	0.272	19.22	0.214E-03	0.00	0.000E+00
10	0.8593E+00	1.0000	23280	2.00	0.269	19.94	0.265E-03	0.00	0.000E+00
10	0.9037E+00	1.0000	23430	2.00	0.270	20.70	0.331E-03	0.00	0.000E+00
10	0.9519E+00	1.0000	23562	2.00	0.276	21.35	0.396E-03	0.00	0.000E+00
10	0.9981E+00	1.0000	23662	2.00	0.274	22.38	0.522E-03	0.00	0.000E+00
10	0.1059E+01	1.0000	23762	2.00	0.275	23.61	0.714E-03	0.00	0.000E+00
10	0.1142E+01	1.0000	23857	2.00	0.272	25.74	0.119E-02	0.00	0.000E+00
10	0.1216E+01	1.0000	23916	2.00	0.284	27.07	0.159E-02	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 1.4405 CRACK DEPTH = 0.2500 TOTAL CYCLES = 23963

NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)

CPU TIME = 60.5 SECONDS

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SAMPLE 3: Surface-Crack Tension under Constant-Amplitude Loading (LFAST = 1)

SPECTRUM FILE = cstamp TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: 2219-T851
YIELD STRESS = 0.4500E+02 ULTIMATE STRENGTH = 0.6500E+02
ELASTIC MODULUS = 0.1000E+05

PLANE STRESS SOLUTION: CONSTRAINT FACTOR = 0.190E+01
BETA = 0.100E+01

DKEFF IS ELASTIC:
CRACK GROWTH CONSTANTS:
C1 = 0.1200E-06 C2 = 3.120 C3 = 2.70 C4 = 0.80 C5 = 0.700E+02
FRACTURE TOUGHNESS PROPERTIES: KF = 0.700E+02 M = 0.00

SURFACE CRACK TENSION: NTYP = 0 AND LTYP = 0
SPECIMEN WIDTH = 0.400E+01 THICKNESS = 0.300E+00
INITIAL CRACK LENGTH (CI) = 0.13600E+00 INITIAL CRACK DEPTH = 0.30000E-01
NOTCH LENGTH (CN) = 0.13600E+00 NOTCH DEPTH = 0.30000E-01
NOTCH HEIGHT = 0.000E+00 ELEMENTS ON STARTER NOTCH (NS) = 1
FINAL CRACK LENGTH (CF) REQUESTED = 0.40000E+01

PROGRAM OPTIONS: LFAST = 1 KOPEN = 1 KCONST = 0 INVERT = 0 LSTEP = 1
ERR = 0.110E+01 PDC = 0.20 NMAX =1000 NIPT = 50 NPRT = 5 NDKE = 0

BLOCK (OR FLIGHT) LOADING: NFOPT = 0 LPRINT = 0 MAXLPR = 0
TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED = 1
NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) = 1

BLOCK 1 NUMBER OF STRESS LEVELS = 1 NSQ = 1 SCALE = 1.00

LEVEL	SMAX	SMIN	CYCLES
1	0.3000E+02	0.1500E+02	1000

EQUIVALENT CRACK-OPENING STRESS CONCEPT IF CRACK LENGTH >= 0.1455
AND TOTAL BLOCKS (OR FLIGHTS) > 2

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
1	0.1360E+00	0.1000	1	1.90	0.500	2.40	0.000E+00	4.90	0.121E-04
1	0.1370E+00	0.1352	617	1.90	0.523	3.03	0.227E-05	5.43	0.189E-04
1	0.1379E+00	0.1567	930	1.90	0.529	3.48	0.371E-05	5.77	0.220E-04
2	0.1389E+00	0.1735	1145	1.90	0.532	3.81	0.508E-05	5.98	0.245E-04
2	0.1399E+00	0.1881	1313	1.90	0.532	4.07	0.646E-05	6.15	0.268E-04
2	0.1409E+00	0.2008	1450	1.90	0.533	4.29	0.773E-05	6.28	0.285E-04
2	0.1419E+00	0.2124	1568	1.90	0.533	4.49	0.909E-05	6.39	0.303E-04
2	0.1429E+00	0.2232	1672	1.90	0.534	4.67	0.103E-04	6.49	0.316E-04
2	0.1439E+00	0.2333	1765	1.90	0.534	4.83	0.115E-04	6.58	0.330E-04
2	0.1450E+00	0.2427	1849	1.90	0.533	4.97	0.129E-04	6.66	0.345E-04

CONVERGENCE IN 2 ITERATIONS
APPLIED STRESS = 0.3000E+02 CRACK LENGTH = 0.14557E+00

ELEMENT	LENGTH	DISPLACEMENT	STRESS	WIDTH	CENTER-
11	0.00000E+00	0.80751E-03	0.000	0.13600E+00	LINE
12	0.16650E-03	0.36146E-03	0.000	0.36752E-02	
13	0.16999E-03	0.31940E-03	0.000	0.17958E-02	
14	0.17208E-03	0.28878E-03	0.000	0.16232E-02	
15	0.17370E-03	0.26131E-03	0.000	0.10276E-02	
16	0.17442E-03	0.24681E-03	0.000	0.20261E-03	
17	0.17468E-03	0.24161E-03	0.000	0.20757E-03	
18	0.17496E-03	0.23604E-03	0.000	0.21312E-03	
19	0.17521E-03	0.23018E-03	0.000	0.20611E-03	
20	0.17545E-03	0.22401E-03	0.000	0.20727E-03	
21	0.17572E-03	0.21721E-03	0.000	0.21133E-03	
22	0.17595E-03	0.20951E-03	0.000	0.20298E-03	CRACK
1	0.17527E-03	0.20062E-03	104.500	0.16199E-03	TIP
2	0.17430E-03	0.19432E-03	104.500	0.16199E-03	
3	0.17238E-03	0.18613E-03	104.500	0.32399E-03	
4	0.16681E-03	0.17211E-03	104.500	0.64798E-03	
5	0.15225E-03	0.15225E-03	104.500	0.97197E-03	
6	0.12719E-03	0.12719E-03	104.500	0.14580E-02	
7	0.97948E-04	0.97948E-04	104.500	0.19439E-02	
8	0.67645E-04	0.67645E-04	104.500	0.24299E-02	
9	0.37100E-04	0.37100E-04	104.500	0.32399E-02	
10	0.80019E-05	0.80019E-05	104.500	0.48598E-02	

PLASTIC ZONE = 0.1620E-01 END OF PLASTIC ZONE

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        CONVERGENCE IN 12   ITERATIONS
        APPLIED STRESS =  0.1500E+02    CRACK LENGTH = 0.14578E+00
 ELEMENT   LENGTH          DISPLACEMENT         STRESS           WIDTH     CENTER-
   11     0.00000E+00      0.42052E-03           0.000        0.13600E+00  LINE
   12     0.16650E-03      0.21834E-03           0.000        0.36752E-02
   13     0.17098E-03      0.19755E-03           0.000        0.34191E-02
   14     0.17370E-03      0.18389E-03           0.000        0.10276E-02
   15     0.17442E-03      0.18029E-03           0.000        0.20261E-03
   16     0.17468E-03      0.17916E-03           0.000        0.20757E-03
   17     0.17496E-03      0.17808E-03           0.000        0.21312E-03
   18     0.17521E-03      0.17709E-03           0.000        0.20611E-03
   19     0.17545E-03      0.17628E-03           0.000        0.20727E-03
   20     0.17572E-03      0.17576E-03          -0.815        0.21133E-03
   21     0.17595E-03      0.17586E-03         -23.132        0.20298E-03
   22     0.20062E-03      0.17618E-03         -55.000        0.20371E-03  CRACK
    1     0.20090E-03      0.17551E-03         -55.000        0.16222E-03   TIP
    2     0.19460E-03      0.17454E-03         -55.000        0.16222E-03
    3     0.18639E-03      0.17262E-03         -55.000        0.32444E-03
    4     0.17235E-03      0.16705E-03         -55.000        0.64889E-03
    5     0.15247E-03      0.15251E-03         -23.909        0.97333E-03
    6     0.12737E-03      0.12741E-03          21.323        0.14600E-02
    7     0.98086E-04      0.98107E-04          40.592        0.19467E-02
    8     0.67740E-04      0.67740E-04          52.015        0.24333E-02
    9     0.37152E-04      0.37150E-04          60.084        0.32444E-02
   10     0.80130E-05      0.80112E-05          66.915        0.48667E-02
        PLASTIC ZONE = 0.1622E-01                          END OF PLASTIC ZONE

BLOCK      C          A/T    CYCLES  ALP  KO/KMAX  DKC    DC/DN      DKA   DA/DN

   2  0.1460E+00 0.2516    1926  1.90  0.536   5.11 0.138E-04   6.73 0.351E-04
   2  0.1470E+00 0.2603    1998  1.90  0.536   5.23 0.150E-04   6.79 0.362E-04

    EQUIVALENT CRACK-OPENING SIF RATIO:  KO/KMAX =  0.534

   4  0.1821E+00 0.4472    3163  1.90  0.534   7.59 0.523E-04   8.06 0.637E-04
   4  0.2281E+00 0.6049    3747  1.90  0.534   9.58 0.113E-03   9.30 0.103E-03
   5  0.2868E+00 0.7625    4106  1.90  0.534  11.79 0.229E-03  10.76 0.168E-03
   5  0.3620E+00 0.9279    4335  1.90  0.534  14.40 0.460E-03  12.45 0.276E-03
   5  0.4615E+00 1.0000    4471  1.90  0.534  18.21 0.109E-02   0.00 0.000E+00
   5  0.5928E+00 1.0000    4563  1.90  0.534  20.74 0.184E-02   0.00 0.000E+00
   5  0.7727E+00 1.0000    4634  1.90  0.534  23.91 0.347E-02   0.00 0.000E+00
   5  0.1036E+01 1.0000    4683  1.90  0.534  28.20 0.863E-02   0.00 0.000E+00

SPECIMEN FAILED:

  CRACK LENGTH =  1.3667     CRACK DEPTH =  0.3000     TOTAL CYCLES =     4701

  NFCODE = 0:  KMAX > C5

  CPU TIME =    0.8  SECONDS
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SAMPLE 4: Corner Crack from Hole under User Specified Loading

SPECTRUM FILE = cstamp          TIME LIMIT =  200.0 SECONDS

MATERIAL PROPERTIES:   7075-T651
YIELD STRESS = 0.7700E+02     ULTIMATE STRENGTH = 0.8500E+02
ELASTIC MODULUS = 0.1040E+05

PLANE STRESS SOLUTION:     CONSTRAINT FACTOR = 0.100E+01
                                        BETA = 0.100E+01

DKEFF IS ELASTIC:
     CRACK GROWTH CONSTANTS:
     C1 =  0.3200E-07   C2 = 3.000   C3 =  0.00   C4 =  0.00   C5 = 0.999E+03
     FRACTURE TOUGHNESS PROPERTIES:    KF = 0.865E+02     M = 0.70


ONE CORNER CRACK AT HOLE: NTYP = -1
     SPECIMEN WIDTH = 0.200E+01     THICKNESS = 0.250E+00
     INITIAL CRACK LENGTH (CI) = 0.14500E+00   INITIAL CRACK DEPTH = 0.20000E-01
     NOTCH LENGTH (CN) = 0.14500E+00    NOTCH DEPTH = 0.20000E-01
     NOTCH HEIGHT = 0.000E+00    ELEMENTS ON STARTER NOTCH (NS) = 2
     FINAL CRACK LENGTH (CF) REQUESTED =  0.20000E+01
     HOLE RADIUS (RAD) =  0.12500E+00

PROGRAM OPTIONS:  LFAST = 0   KOPEN = 1   KCONST = 0   INVERT = 0   LSTEP = 1
  ERR = 0.162E+01  PDC = 0.20  NMAX =1000  NIPT = 1000  NPRT = 20  NDKE = 0

  BLOCK (OR FLIGHT) LOADING:  NFOPT = 1     LPRINT = 0     MAXLPR =    0
     TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED =  100
     NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) =    5

    BLOCK  1     NUMBER OF STRESS LEVELS =   6    NSQ =   1     SCALE =  15.00
                LEVEL      SMAX          SMIN           CYCLES
                  1     0.1871E+02    0.1350E+02            5
                  2     0.1977E+02    0.1245E+02            2
                  3     0.2101E+02    0.1172E+02            1
                  4     0.1977E+02    0.1245E+02            1
                  5     0.1871E+02    0.1350E+02            4
                  6     0.1500E+02    0.1354E+01            1

    BLOCK  2     NUMBER OF STRESS LEVELS =  10    NSQ =   5     SCALE =  15.00
                LEVEL      SMAX          SMIN           CYCLES
                  1     0.1871E+02    0.1350E+02            5
                  2     0.1977E+02    0.1245E+02            3
                  3     0.2101E+02    0.1172E+02            2
                  4     0.2239E+02    0.1048E+02            1
                  5     0.2371E+02    0.9485E+01            1
                  6     0.2239E+02    0.1048E+02            1
                  7     0.2101E+02    0.1172E+02            1
                  8     0.1977E+02    0.1245E+02            2
                  9     0.1871E+02    0.1350E+02            5
                 10     0.1500E+02    0.0000E+00            1
```

BLOCK 3 NUMBER OF STRESS LEVELS = 11 NSQ = 10 SCALE = 15.00

LEVEL	SMAX	SMIN	CYCLES
1	0.1871E+02	0.1350E+02	5
2	0.1977E+02	0.1245E+02	3
3	0.2101E+02	0.1172E+02	2
4	0.2239E+02	0.1048E+02	2
5	0.2371E+02	0.9485E+01	1
6	0.2519E+02	0.8386E+01	1
7	0.2239E+02	0.1048E+02	1
8	0.2101E+02	0.1172E+02	1
9	0.1977E+02	0.1245E+02	2
10	0.1871E+02	0.1350E+02	5
11	0.1500E+02	0.0000E+00	1

BLOCK 4 NUMBER OF STRESS LEVELS = 15 NSQ = 50 SCALE = 15.00

LEVEL	SMAX	SMIN	CYCLES
1	0.1871E+02	0.1350E+02	5
2	0.1977E+02	0.1245E+02	3
3	0.2101E+02	0.1172E+02	2
4	0.2239E+02	0.1048E+02	3
5	0.2371E+02	0.9485E+01	1
6	0.2519E+02	0.8386E+01	1
7	0.2661E+02	0.6872E+01	1
8	0.2819E+02	0.5613E+01	1
9	0.2661E+02	0.6872E+01	1
10	0.2371E+02	0.9485E+01	1
11	0.2239E+02	0.1048E+02	2
12	0.2101E+02	0.1172E+02	1
13	0.1977E+02	0.1245E+02	2
14	0.1871E+02	0.1350E+02	5
15	0.1500E+02	0.0000E+00	1

BLOCK 5 NUMBER OF STRESS LEVELS = 17 NSQ = 100 SCALE = 15.00

LEVEL	SMAX	SMIN	CYCLES
1	0.1871E+02	0.1350E+02	5
2	0.1977E+02	0.1245E+02	3
3	0.2101E+02	0.1172E+02	2
4	0.2239E+02	0.1048E+02	3
5	0.2371E+02	0.9485E+01	2
6	0.2519E+02	0.8386E+01	1
7	0.2661E+02	0.6872E+01	2
8	0.2819E+02	0.5613E+01	1
9	0.2968E+02	0.3872E+01	2
10	0.2661E+02	0.6872E+01	1
11	0.2519E+02	0.8386E+01	1
12	0.2371E+02	0.9485E+01	1
13	0.2239E+02	0.1048E+02	3
14	0.2101E+02	0.1172E+02	1
15	0.1977E+02	0.1245E+02	2
16	0.1871E+02	0.1350E+02	5
17	0.1500E+02	0.0000E+00	1

NOTE: KO/KMAX AND SIF BASED ON HIGHEST AND LOWEST APPLIED STRESS IN SEQUENCE

BLOCK	C'-RAD	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
1	0.2001E-01	0.0801	1	1.00	0.000	10.97	0.106E-04	13.11	0.181E-04
1116	0.4521E-01	0.2334	17820	1.00	0.333	15.58	0.192E-05	18.34	0.184E-05
2146	0.7355E-01	0.4147	34273	1.00	0.473	18.40	0.772E-06	21.65	0.126E-05
3112	0.1096E+00	0.6349	49716	1.00	0.491	20.93	0.156E-05	23.90	0.232E-05
4028	0.1489E+00	0.8468	64346	1.00	0.491	23.38	0.110E-05	25.33	0.140E-05
4863	0.1951E+00	1.0000	77695	1.00	0.344	26.19	0.113E-04	0.00	0.000E+00
5707	0.2507E+00	1.0000	91186	1.00	0.504	27.55	0.563E-05	0.00	0.000E+00
6525	0.3136E+00	1.0000	104252	1.00	0.361	29.11	0.221E-04	0.00	0.000E+00
7388	0.3842E+00	1.0000	118037	1.00	0.498	30.87	0.443E-05	0.00	0.000E+00
8222	0.4680E+00	1.0000	131374	1.00	0.486	32.95	0.123E-04	0.00	0.000E+00
9038	0.5793E+00	1.0000	144408	1.00	0.482	35.69	0.167E-04	0.00	0.000E+00
9695	0.6981E+00	1.0000	154910	1.00	0.462	38.66	0.878E-05	0.00	0.000E+00
10345	0.8649E+00	1.0000	165294	1.00	0.297	43.07	0.241E-03	0.00	0.000E+00
10877	0.1116E+01	1.0000	173797	1.00	0.367	50.92	0.831E-04	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 1.3067 CRACK DEPTH = 0.2500 TOTAL CYCLES = 175153

NFCODE = 6: CRACK LENGTH PLUS PLASTIC ZONE EXCEEDS WIDTH

CPU TIME = 18.8 SECONDS

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SAMPLE 5: Corner Crack at Hole - Space Shuttle Spectrum (LFAST = 3)

SPECTRUM FILE = stsn TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: 7075-T7351
YIELD STRESS = 0.4470E+03 ULTIMATE STRENGTH = 0.5200E+03
ELASTIC MODULUS = 0.7110E+05

PLANE STRAIN SOLUTION: CONSTRAINT FACTOR = 0.250E+01
BETA = 0.100E+01 POISSONS RATIO = 0.330E+00

DKEFF IS ELASTIC:
CRACK GROWTH RATES FROM TABLE LOOKUP (NDKTH = 0):

DKEFF	RATE
0.1000E+01	0.1000E-10
0.2000E+01	0.2000E-08
0.7000E+01	0.1000E-06
0.1200E+02	0.4700E-06
0.2000E+02	0.2500E-05
0.3000E+02	0.1200E-04

THRESHOLD CONSTANTS: C3 = 2.50 C4 = 1.00

FRACTURE TOUGHNESS PROPERTIES: KF = 0.800E+02 M = 0.00

ONE CORNER CRACK AT HOLE: NTYP = -1
SPECIMEN WIDTH = 0.350E-01   THICKNESS = 0.140E-01
INITIAL CRACK LENGTH (CI) = 0.13750E-01   INITIAL CRACK DEPTH = 0.12000E-02
NOTCH LENGTH (CN) = 0.13750E-01   NOTCH DEPTH = 0.12000E-02
NOTCH HEIGHT = 0.000E+00   ELEMENTS ON STARTER NOTCH (NS) = 2
FINAL CRACK LENGTH (CF) REQUESTED = 0.35000E-01
HOLE RADIUS (RAD) = 0.75000E-02

PROGRAM OPTIONS: LFAST = 3   KOPEN = 1   KCONST = 0   INVERT = 1   LSTEP = 1
ERR = 0.967E+01 PDC = 0.20 NMAX =1000 NIPT = 3000 NPRT = 10 NDKE = 0

BLOCK (OR FLIGHT) LOADING: NFOPT = 5   LPRINT = 1   MAXLPR = 2
TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED = 2
NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) = 2

CONSTANT CRACK-OPENING CONCEPT: KO/KMAX = 0.283

SHORT SHUTTLE SPECTRUM: HIGHEST STRESS = 0.1500E+03

NOTE: KO/KMAX AND SIF BASED ON HIGHEST AND LOWEST APPLIED STRESS IN SEQUENCE

===
NLR GENERATED STS TEST SEQUENCE
11430 LOADING REVERSALS -30 => X <= 100 (= 1 FLIGHT)
===

BLOCK	SMAX	SMIN	CYCLES	TOTAL CYCLES
1	0.7500E+02	0.0000E+00	1	1
1	0.6750E+02	0.7500E+01	6	7
1	0.3000E+02	-0.3000E+02	11	18
1	0.6000E+02	0.1500E+02	523	541
1	0.6750E+02	0.7500E+01	813	1354
1	0.6750E+02	0.3000E+02	2000	3354
1	0.6750E+02	0.3000E+02	999	4353
1	0.6750E+02	-0.4500E+02	1	4354
1	0.1275E+03	0.7500E+01	1	4355
1	0.1050E+03	0.7500E+01	1	4356
1	0.1050E+03	0.3000E+02	1	4357
1	0.3750E+02	-0.3750E+02	7	4364
2	0.8250E+02	0.2250E+02	14	14
2	0.1050E+03	0.6000E+02	88	102
2	0.6750E+02	0.7500E+01	542	644
2	0.1500E+03	-0.4500E+02	1	645
2	0.1350E+03	0.6750E+02	230	875
2	0.7500E+02	0.0000E+00	2	877
2	0.1125E+03	0.5250E+02	4	881
2	0.1125E+03	-0.3000E+02	1	882
2	0.3000E+02	-0.3000E+02	37	919
2	0.1275E+03	0.8250E+02	29	948
2	0.1275E+03	0.3000E+02	1	949
2	0.6750E+02	0.3000E+02	400	1349

BLOCK	C'-RAD	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
11	0.6267E-02	0.1438	31000	2.50	0.283	12.44	0.364E-09	32.65	0.203E-07
25	0.6471E-02	0.2964	70165	2.50	0.283	22.02	0.593E-08	40.08	0.385E-07
37	0.7169E-02	0.4971	106413	2.50	0.283	30.13	0.158E-07	42.54	0.463E-07
48	0.8392E-02	0.6984	136538	2.50	0.283	36.07	0.533E-06	44.27	0.104E-05
57	0.1000E-01	0.8852	161495	2.50	0.283	41.84	0.439E-07	46.64	0.616E-07
63	0.1199E-01	1.0000	181340	2.50	0.283	49.84	0.757E-07	0.00	0.000E+00
69	0.1450E-01	1.0000	195437	2.50	0.283	54.41	0.995E-07	0.00	0.000E+00
74	0.1761E-01	1.0000	210526	2.50	0.283	62.24	0.147E-06	0.00	0.000E+00
77	0.2248E-01	1.0000	221397	2.50	0.283	86.05	0.371E-06	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 0.0350 CRACK DEPTH = 0.0140 TOTAL CYCLES = 222378

NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)

CPU TIME = 0.4 SECONDS

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SAMPLE 6: Small Crack at Notch under Mini-TWIST (NALP = 1 Option)

SPECTRUM FILE = cstamp TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: 7075-T6
YIELD STRESS = 0.5200E+03 ULTIMATE STRENGTH = 0.5750E+03
ELASTIC MODULUS = 0.6960E+05

PLANE-STRAIN-TO-PLANE-STRESS SOLUTION:
(ALP = ALP1 TO ALP2 AND BETA = BETA1 TO BETA2)

DKEFF IS ELASTIC:
CRACK GROWTH RATES (dc/dN) FROM TABLE LOOKUP (NDKTH = 0):

DKEFF	RATE
0.9000E+00	0.1000E-10
0.1350E+01	0.1200E-08
0.3400E+01	0.1000E-07
0.5200E+01	0.1000E-06
0.1190E+02	0.1000E-05
0.1880E+02	0.1000E-04
0.2900E+02	0.1000E-03

THRESHOLD CONSTANTS: C3 = 0.80 C4 = 0.00

FRACTURE TOUGHNESS PROPERTIES: KF = 0.500E+02 M = 0.00

CRACK GROWTH RATES (da/dN) FROM TABLE LOOKUP (NDKTH = 0):

DKEFF	RATE
0.8000E+00	0.1000E-10
0.1250E+01	0.1000E-08
0.3400E+01	0.1000E-07
0.1400E+02	0.1000E-05

THRESHOLD CONSTANTS: C3 = 1.00 C4 = 0.00

FRACTURE TOUGHNESS PROPERTIES: KF = 0.500E+02 M = 0.00

RATE AT START OF TRANSITION = 0.5000E-06 WITH ALP1 = 1.80 AND BETA1 = 1.00
RATE AT END OF TRANSITION = 0.5000E-05 WITH ALP2 = 1.20 AND BETA2 = 1.00

SURFACE CRACK AT CENTER OF SEMI-CIRCULAR EDGE NOTCH: NTYP = -7
SPECIMEN WIDTH = 0.500E-01 THICKNESS = 0.115E-02
INITIAL CRACK LENGTH (CI) = 0.31840E-02 INITIAL CRACK DEPTH = 0.25000E-05
NOTCH LENGTH (CN) = 0.31840E-02 NOTCH DEPTH = 0.25000E-05
NOTCH HEIGHT = 0.250E-05 ELEMENTS ON STARTER NOTCH (NS) = 2
FINAL CRACK LENGTH (CF) REQUESTED = 0.50000E-01
HOLE RADIUS (RAD) = 0.31750E-02
KT = 0.315E+01 NBCF OPTION = 1

PROGRAM OPTIONS: LFAST = 0 KOPEN = 1 KCONST = 0 INVERT = 0 LSTEP = 1
ERR = 0.109E+02 PDC = 0.20 NMAX =1000 NIPT = 4000 NPRT = 30 NDKE = 0

BLOCK (OR FLIGHT) LOADING: NFOPT = 3 LPRINT = 0 MAXLPR = 0
TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED = 4000
NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) = 10

MINI-TWIST FLIGHT-LOAD SEQUENCE: MEAN STRESS = 0.9000E+02

NOTE: KO/KMAX AND SIF BASED ON HIGHEST AND LOWEST APPLIED STRESS IN SEQUENCE

BLOCK	C'-RAD	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
1	0.9000E-05	0.0022	2	1.80	-0.231	1.27	0.000E+00	2.51	0.119E-08
1967	0.9084E-05	0.0041	29042	1.80	-0.163	2.06	0.000E+00	3.08	0.000E+00
3818	0.1001E-04	0.0067	59042	1.80	-0.016	2.87	0.000E+00	3.53	0.000E+00
5756	0.1203E-04	0.0102	89042	1.80	-0.022	3.60	0.000E+00	3.94	0.000E+00
7615	0.1713E-04	0.0167	118059	1.80	0.185	4.62	0.000E+00	4.73	0.000E+00
9316	0.3189E-04	0.0316	144312	1.80	0.218	6.23	0.171E-08	6.30	0.175E-08
10720	0.6726E-04	0.0641	164960	1.80	0.260	8.68	0.262E-08	8.92	0.278E-08
11564	0.1267E-03	0.1183	179860	1.80	0.133	11.55	0.213E-07	12.06	0.169E-07
12193	0.2064E-03	0.1879	190616	1.80	0.224	13.93	0.910E-08	15.01	0.111E-07
12831	0.3085E-03	0.2783	199373	1.80	0.267	16.20	0.106E-07	18.19	0.151E-07
13184	0.4165E-03	0.3702	204576	1.80	0.257	17.93	0.670E-07	21.15	0.536E-07
13384	0.5263E-03	0.4683	207999	1.80	0.218	19.35	0.101E-06	23.87	0.794E-07
13594	0.6318E-03	0.5706	210912	1.80	0.216	20.65	0.364E-08	26.57	0.649E-08
13708	0.8368E-03	0.7841	213099	1.75	0.284	22.92	0.856E-08	32.41	0.248E-07
14138	0.1010E-02	1.0000	218348	1.55	0.342	37.30	0.127E-06	0.00	0.000E+00
14211	0.1118E-02	1.0000	219369	1.63	0.340	38.16	0.134E-06	0.00	0.000E+00
14240	0.1212E-02	1.0000	219744	1.61	0.099	38.83	0.474E-06	0.00	0.000E+00
14273	0.1289E-02	1.0000	220142	1.56	0.284	39.35	0.249E-06	0.00	0.000E+00
14289	0.1378E-02	1.0000	220455	1.80	0.318	39.93	0.348E-08	0.00	0.000E+00
14317	0.1467E-02	1.0000	220792	1.78	0.282	40.47	0.631E-06	0.00	0.000E+00
14324	0.1570E-02	1.0000	221047	1.79	0.297	41.07	0.301E-06	0.00	0.000E+00
14334	0.1685E-02	1.0000	221325	1.67	0.296	41.72	0.319E-06	0.00	0.000E+00
14365	0.1803E-02	1.0000	221784	1.37	0.293	42.35	0.176E-06	0.00	0.000E+00
14391	0.1914E-02	1.0000	222221	1.76	0.332	42.94	0.226E-06	0.00	0.000E+00
14415	0.2029E-02	1.0000	222652	1.67	0.312	43.54	0.325E-06	0.00	0.000E+00
14437	0.2169E-02	1.0000	223073	1.55	0.334	44.25	0.558E-06	0.00	0.000E+00
14474	0.2289E-02	1.0000	223563	1.80	0.314	44.86	0.128E-06	0.00	0.000E+00
14504	0.2435E-02	1.0000	224033	1.56	0.318	45.58	0.172E-06	0.00	0.000E+00
14543	0.2596E-02	1.0000	224527	1.54	0.331	46.38	0.103E-06	0.00	0.000E+00
14567	0.2742E-02	1.0000	225048	1.41	0.220	47.09	0.811E-06	0.00	0.000E+00

14598	0.2878E-02	1.0000	225515	1.40	0.337	47.76	0.271E-06	0.00	0.000E+00
14626	0.3040E-02	1.0000	225993	1.38	0.295	48.55	0.493E-06	0.00	0.000E+00
14678	0.3188E-02	1.0000	226572	1.76	0.310	49.29	0.168E-06	0.00	0.000E+00
14683	0.3445E-02	1.0000	226878	1.41	0.293	50.55	0.912E-08	0.00	0.000E+00
14761	0.3755E-02	1.0000	228024	1.20	0.378	52.06	0.175E-06	0.00	0.000E+00
14796	0.4039E-02	1.0000	228786	1.41	0.288	53.51	0.702E-06	0.00	0.000E+00
14852	0.4371E-02	1.0000	229659	1.59	0.209	55.19	0.183E-06	0.00	0.000E+00
14856	0.4969E-02	1.0000	230134	1.27	0.311	58.25	0.131E-05	0.00	0.000E+00
15168	0.5812E-02	1.0000	235466	1.20	0.413	62.67	0.140E-06	0.00	0.000E+00
15260	0.6338E-02	1.0000	237398	1.20	0.401	65.53	0.766E-06	0.00	0.000E+00
15353	0.6914E-02	1.0000	238649	1.20	0.354	68.77	0.576E-06	0.00	0.000E+00
15446	0.7630E-02	1.0000	240055	1.43	0.346	72.96	0.290E-06	0.00	0.000E+00
15524	0.8249E-02	1.0000	241139	1.20	0.357	76.64	0.789E-06	0.00	0.000E+00
15530	0.8852E-02	1.0000	241433	1.33	0.312	80.40	0.147E-05	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 0.0126   CRACK DEPTH = 0.0012   TOTAL CYCLES = 241725

NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)

CPU TIME = 72.6 SECONDS

****

SAMPLE 7: Compact Specimen under Stress-Intensity Factor Loading

SPECTRUM FILE = cstamp   TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: FVS0812
YIELD STRESS = 0.5700E+02   ULTIMATE STRENGTH = 0.6600E+02
ELASTIC MODULUS = 0.1280E+05

PLANE-STRAIN-TO-PLANE-STRESS SOLUTION:
(ALP = ALP1 TO ALP2 AND BETA = BETA1 TO BETA2)

DKEFF IS ELASTIC:
CRACK GROWTH RATES FROM TABLE LOOKUP (NDKTH = 0):

DKEFF	RATE
0.6500E+00	0.1000E-08
0.9400E+00	0.1000E-07
0.1400E+01	0.1000E-06
0.3100E+01	0.1000E-05
0.7000E+01	0.1000E-04
0.1130E+02	0.4400E-04
0.2200E+02	0.1000E-02

THRESHOLD CONSTANTS: C3 = 0.00   C4 = 0.00

FRACTURE TOUGHNESS PROPERTIES: KF = 0.400E+02   M = 0.00

RATE AT START OF TRANSITION = 0.4000E-05 WITH ALP1 = 2.40 AND BETA1 = 1.00
RATE AT END OF TRANSITION = 0.6000E-03 WITH ALP2 = 1.90 AND BETA2 = 1.00

```
COMPACT SPECIMEN: NTYP = 2
    SPECIMEN WIDTH = 0.200E+01      THICKNESS = 0.250E+00
    INITIAL CRACK LENGTH (CI) = 0.51000E+00   INITIAL CRACK DEPTH = 0.25000E+00
    NOTCH LENGTH (CN) = 0.48000E+00    NOTCH DEPTH = 0.25000E+00
    NOTCH HEIGHT = 0.000E+00    ELEMENTS ON STARTER NOTCH (NS) = 1
    FINAL CRACK LENGTH (CF) REQUESTED =  0.65000E+00

PROGRAM OPTIONS:  LFAST = 0   KOPEN = 1   KCONST = 1   INVERT = 0   LSTEP = 1
  ERR = 0.123E+01  PDC = 0.20  NMAX =1000  NIPT = 2000  NPRT = 10  NDKE = 1

  PRECRACKING FROM STARTER NOTCH:
  MAX SIF = 0.1650E+02     MIN SIF = 0.1650E+01
```

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKEC	DC/DN	DKEA	DA/DN
0	0.4834E+00	1.0000	46	2.17	0.280	11.87	0.555E-04	0.00	0.000E+00
0	0.4866E+00	1.0000	114	2.17	0.318	11.25	0.434E-04	0.00	0.000E+00
0	0.4900E+00	1.0000	193	2.17	0.330	11.05	0.411E-04	0.00	0.000E+00
0	0.4932E+00	1.0000	273	2.17	0.337	10.94	0.398E-04	0.00	0.000E+00
0	0.4964E+00	1.0000	353	2.17	0.341	10.87	0.391E-04	0.00	0.000E+00
0	0.4995E+00	1.0000	433	2.17	0.343	10.84	0.387E-04	0.00	0.000E+00
0	0.5026E+00	1.0000	513	2.17	0.344	10.83	0.386E-04	0.00	0.000E+00
0	0.5056E+00	1.0000	593	2.17	0.345	10.81	0.384E-04	0.00	0.000E+00
0	0.5087E+00	1.0000	673	2.17	0.345	10.81	0.383E-04	0.00	0.000E+00

```
  BLOCK (OR FLIGHT) LOADING:  NFOPT = 1     LPRINT = 0     MAXLPR =    0
     TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED =     2
     NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) =     2

    BLOCK  1      NUMBER OF SIF LEVELS =   1    NSQ =   1     SCALE =   1.00
               LEVEL      KMAX              KMIN              CYCLES
                 1      0.3300E+02      0.3300E+01                1

    BLOCK  2      NUMBER OF SIF LEVELS =   1    NSQ =   2     SCALE =   1.00
               LEVEL      KMAX              KMIN              CYCLES
                 1      0.1650E+02      0.1650E+01           100000

  NOTE: KO/KMAX BASED ON "CURRENT" APPLIED KMAX IN SEQUENCE
```

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKEC	DC/DN	DKEA	DA/DN
1	0.5125E+00	1.0000	1	1.90	0.187	26.84	0.254E-02	0.00	0.000E+00
2	0.5151E+00	1.0000	133	2.17	0.510	8.09	0.156E-04	0.00	0.000E+00
2	0.5176E+00	1.0000	372	2.17	0.610	6.44	0.791E-05	0.00	0.000E+00
2	0.5201E+00	1.0000	814	2.17	0.682	5.24	0.441E-05	0.00	0.000E+00
2	0.5226E+00	1.0000	1523	2.17	0.722	4.59	0.303E-05	0.00	0.000E+00
2	0.5251E+00	1.0000	2364	2.17	0.721	4.60	0.305E-05	0.00	0.000E+00
2	0.5275E+00	1.0000	3079	2.17	0.696	5.01	0.388E-05	0.00	0.000E+00
2	0.5300E+00	1.0000	3592	2.17	0.651	5.76	0.576E-05	0.00	0.000E+00
2	0.5325E+00	1.0000	3951	2.17	0.606	6.51	0.814E-05	0.00	0.000E+00
2	0.5350E+00	1.0000	4210	2.17	0.559	7.28	0.113E-04	0.00	0.000E+00
2	0.5375E+00	1.0000	4404	2.17	0.516	7.98	0.150E-04	0.00	0.000E+00
2	0.5400E+00	1.0000	4548	2.17	0.474	8.68	0.195E-04	0.00	0.000E+00
2	0.5426E+00	1.0000	4660	2.17	0.432	9.37	0.246E-04	0.00	0.000E+00
2	0.5452E+00	1.0000	4761	2.17	0.419	9.59	0.265E-04	0.00	0.000E+00
2	0.5478E+00	1.0000	4856	2.17	0.412	9.71	0.275E-04	0.00	0.000E+00

2	0.5503E+00	1.0000	4946	2.17	0.406	9.80	0.283E-04	0.00	0.000E+00
2	0.5529E+00	1.0000	5036	2.17	0.400	9.90	0.292E-04	0.00	0.000E+00
2	0.5555E+00	1.0000	5126	2.17	0.397	9.95	0.297E-04	0.00	0.000E+00
2	0.5582E+00	1.0000	5216	2.17	0.392	10.04	0.305E-04	0.00	0.000E+00
2	0.5608E+00	1.0000	5300	2.17	0.390	10.06	0.307E-04	0.00	0.000E+00
2	0.5633E+00	1.0000	5380	2.17	0.385	10.16	0.316E-04	0.00	0.000E+00
2	0.5659E+00	1.0000	5460	2.17	0.382	10.20	0.321E-04	0.00	0.000E+00
2	0.5684E+00	1.0000	5540	2.17	0.379	10.25	0.325E-04	0.00	0.000E+00
2	0.5711E+00	1.0000	5620	2.17	0.376	10.29	0.329E-04	0.00	0.000E+00
2	0.5737E+00	1.0000	5700	2.17	0.375	10.32	0.332E-04	0.00	0.000E+00
2	0.5764E+00	1.0000	5780	2.17	0.373	10.35	0.335E-04	0.00	0.000E+00
2	0.5791E+00	1.0000	5860	2.17	0.371	10.37	0.337E-04	0.00	0.000E+00
2	0.5818E+00	1.0000	5940	2.17	0.370	10.40	0.340E-04	0.00	0.000E+00
2	0.5845E+00	1.0000	6020	2.17	0.369	10.42	0.342E-04	0.00	0.000E+00
2	0.5873E+00	1.0000	6100	2.17	0.368	10.43	0.344E-04	0.00	0.000E+00
2	0.5900E+00	1.0000	6180	2.17	0.366	10.46	0.347E-04	0.00	0.000E+00
2	0.5928E+00	1.0000	6260	2.17	0.365	10.47	0.348E-04	0.00	0.000E+00
2	0.5956E+00	1.0000	6340	2.17	0.364	10.49	0.349E-04	0.00	0.000E+00
2	0.5983E+00	1.0000	6417	2.17	0.362	10.52	0.353E-04	0.00	0.000E+00
2	0.6009E+00	1.0000	6492	2.17	0.361	10.54	0.355E-04	0.00	0.000E+00
2	0.6035E+00	1.0000	6567	2.17	0.361	10.55	0.356E-04	0.00	0.000E+00
2	0.6062E+00	1.0000	6642	2.17	0.359	10.57	0.358E-04	0.00	0.000E+00
2	0.6087E+00	1.0000	6713	2.17	0.362	10.52	0.353E-04	0.00	0.000E+00
2	0.6112E+00	1.0000	6783	2.17	0.362	10.53	0.354E-04	0.00	0.000E+00
2	0.6136E+00	1.0000	6853	2.17	0.361	10.55	0.356E-04	0.00	0.000E+00
2	0.6161E+00	1.0000	6923	2.17	0.360	10.56	0.356E-04	0.00	0.000E+00
2	0.6186E+00	1.0000	6993	2.17	0.360	10.56	0.357E-04	0.00	0.000E+00
2	0.6211E+00	1.0000	7063	2.17	0.359	10.58	0.359E-04	0.00	0.000E+00
2	0.6236E+00	1.0000	7133	2.17	0.359	10.58	0.359E-04	0.00	0.000E+00
2	0.6262E+00	1.0000	7203	2.17	0.358	10.59	0.359E-04	0.00	0.000E+00
2	0.6287E+00	1.0000	7273	2.17	0.358	10.59	0.360E-04	0.00	0.000E+00
2	0.6312E+00	1.0000	7343	2.17	0.358	10.59	0.360E-04	0.00	0.000E+00
2	0.6337E+00	1.0000	7413	2.17	0.357	10.60	0.362E-04	0.00	0.000E+00
2	0.6363E+00	1.0000	7483	2.17	0.357	10.60	0.361E-04	0.00	0.000E+00
2	0.6388E+00	1.0000	7553	2.17	0.357	10.61	0.363E-04	0.00	0.000E+00
2	0.6413E+00	1.0000	7623	2.17	0.357	10.61	0.362E-04	0.00	0.000E+00
2	0.6439E+00	1.0000	7693	2.17	0.357	10.62	0.363E-04	0.00	0.000E+00
2	0.6464E+00	1.0000	7763	2.17	0.356	10.63	0.364E-04	0.00	0.000E+00
2	0.6489E+00	1.0000	7833	2.17	0.356	10.63	0.364E-04	0.00	0.000E+00

CRACK LENGTH EXCEEDS INPUT VALUE FOR CF

CPU TIME = 9.5 SECONDS

****

SAMPLE 8: Center-Crack Tension under NFOPT = 8 Option

SPECTRUM FILE = snfopt8   TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: 2024-T3
YIELD STRESS = 0.5200E+02   ULTIMATE STRENGTH = 0.7200E+02
ELASTIC MODULUS = 0.1040E+05

PLANE STRESS SOLUTION: CONSTRAINT FACTOR = 0.100E+01
BETA = 0.100E+01

```
DKEFF IS ELASTIC:
     CRACK GROWTH CONSTANTS:
     C1 =  0.2870E-08   C2 = 4.070   C3 =  0.00   C4 =  0.00   C5 = 0.999E+03
     FRACTURE TOUGHNESS PROPERTIES:    KF = 0.400E+03     M = 1.00


CENTER CRACK TENSION: NTYP = 1
     SPECIMEN WIDTH = 0.120E+02     THICKNESS = 0.500E-01
     INITIAL CRACK LENGTH (CI) = 0.20000E+00   INITIAL CRACK DEPTH = 0.50000E-01
     NOTCH LENGTH (CN) = 0.10000E+00    NOTCH DEPTH = 0.50000E-01
     NOTCH HEIGHT = 0.000E+00    ELEMENTS ON STARTER NOTCH (NS) = 1
     FINAL CRACK LENGTH (CF) REQUESTED =  0.12000E+02

PROGRAM OPTIONS:  LFAST = 0   KOPEN = 1   KCONST = 0   INVERT = 0   LSTEP = 1
  ERR = 0.124E+01  PDC = 0.20  NMAX =1000  NIPT = 3000  NPRT =  3  NDKE = 0

  PRECRACKING FROM STARTER NOTCH:
  MAX STRESS = 0.2000E+02     MIN STRESS =  0.2000E+01
```

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
0	0.1022E+00	1.0000	93	1.00	0.262	10.20	0.161E-04	0.00	0.000E+00
0	0.1044E+00	1.0000	316	1.00	0.374	10.31	0.858E-05	0.00	0.000E+00
0	0.1067E+00	1.0000	647	1.00	0.425	10.42	0.635E-05	0.00	0.000E+00
0	0.1090E+00	1.0000	1050	1.00	0.450	10.53	0.555E-05	0.00	0.000E+00
0	0.1114E+00	1.0000	1495	1.00	0.463	10.65	0.523E-05	0.00	0.000E+00
0	0.1138E+00	1.0000	1967	1.00	0.472	10.76	0.513E-05	0.00	0.000E+00
0	0.1163E+00	1.0000	2454	1.00	0.478	10.88	0.509E-05	0.00	0.000E+00
0	0.1188E+00	1.0000	2948	1.00	0.482	11.00	0.517E-05	0.00	0.000E+00
0	0.1214E+00	1.0000	3441	1.00	0.485	11.12	0.529E-05	0.00	0.000E+00
0	0.1241E+00	1.0000	3934	1.00	0.487	11.24	0.542E-05	0.00	0.000E+00
0	0.1268E+00	1.0000	4422	1.00	0.489	11.36	0.560E-05	0.00	0.000E+00
0	0.1296E+00	1.0000	4904	1.00	0.490	11.48	0.579E-05	0.00	0.000E+00
0	0.1324E+00	1.0000	5378	1.00	0.491	11.61	0.602E-05	0.00	0.000E+00
0	0.1353E+00	1.0000	5845	1.00	0.491	11.73	0.628E-05	0.00	0.000E+00
0	0.1382E+00	1.0000	6303	1.00	0.491	11.86	0.652E-05	0.00	0.000E+00
0	0.1412E+00	1.0000	6752	1.00	0.492	11.99	0.678E-05	0.00	0.000E+00
0	0.1443E+00	1.0000	7194	1.00	0.492	12.12	0.707E-05	0.00	0.000E+00
0	0.1474E+00	1.0000	7628	1.00	0.494	12.25	0.731E-05	0.00	0.000E+00
0	0.1506E+00	1.0000	8052	1.00	0.493	12.38	0.768E-05	0.00	0.000E+00
0	0.1539E+00	1.0000	8468	1.00	0.493	12.52	0.800E-05	0.00	0.000E+00
0	0.1573E+00	1.0000	8876	1.00	0.493	12.65	0.836E-05	0.00	0.000E+00
0	0.1607E+00	1.0000	9276	1.00	0.494	12.79	0.871E-05	0.00	0.000E+00
0	0.1642E+00	1.0000	9668	1.00	0.494	12.93	0.910E-05	0.00	0.000E+00
0	0.1678E+00	1.0000	10052	1.00	0.494	13.07	0.948E-05	0.00	0.000E+00
0	0.1715E+00	1.0000	10428	1.00	0.494	13.21	0.992E-05	0.00	0.000E+00
0	0.1752E+00	1.0000	10796	1.00	0.495	13.36	0.103E-04	0.00	0.000E+00
0	0.1790E+00	1.0000	11156	1.00	0.495	13.50	0.107E-04	0.00	0.000E+00
0	0.1829E+00	1.0000	11509	1.00	0.495	13.65	0.112E-04	0.00	0.000E+00
0	0.1869E+00	1.0000	11854	1.00	0.495	13.80	0.117E-04	0.00	0.000E+00
0	0.1910E+00	1.0000	12192	1.00	0.495	13.95	0.123E-04	0.00	0.000E+00
0	0.1952E+00	1.0000	12521	1.00	0.495	14.10	0.128E-04	0.00	0.000E+00
0	0.1994E+00	1.0000	12845	1.00	0.495	14.25	0.134E-04	0.00	0.000E+00

BLOCK (OR FLIGHT) LOADING: NFOPT = 8 LPRINT = 1 MAXLPR = 10
TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED = 2
NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) = 2

SPECTRUM LOAD SEQUENCE (NFOPT = 8): MAX STRESS = 0.3500E+02

NOTE: KO/KMAX AND SIF BASED ON HIGHEST AND LOWEST APPLIED STRESS IN SEQUENCE
SPECTRUM: LIST OF STRESS POINTS

BLOCK	ACCUMULATIVE POINTS	CYCLES
1	2400	1200
2	2678	1339

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKC	DC/DN	DKA	DA/DN
1	0.2040E+00	1.0000	209	1.00	0.321	31.86	0.761E-04	0.00	0.000E+00
1	0.2161E+00	1.0000	562	1.00	0.086	32.79	0.233E-03	0.00	0.000E+00
1	0.2312E+00	1.0000	1158	1.00	0.285	33.92	0.614E-04	0.00	0.000E+00

BLOCK	ACCUMULATIVE POINTS	CYCLES
1	2400	1200
2	2678	1339

3	0.2470E+00	1.0000	1634	1.00	0.355	35.06	0.310E-04	0.00	0.000E+00
4	0.2660E+00	1.0000	2596	1.00	0.408	36.39	0.417E-04	0.00	0.000E+00

BLOCK	ACCUMULATIVE POINTS	CYCLES
1	2400	1200
2	2678	1339

5	0.2802E+00	1.0000	3219	1.00	0.259	37.34	0.253E-03	0.00	0.000E+00

BLOCK	ACCUMULATIVE POINTS	CYCLES
1	2400	1200
2	2678	1339

7	0.2989E+00	1.0000	4623	1.00	0.392	38.57	0.550E-04	0.00	0.000E+00
7	0.3180E+00	1.0000	5166	1.00	0.423	39.79	0.134E-03	0.00	0.000E+00

BLOCK	ACCUMULATIVE POINTS	CYCLES
1	2400	1200
2	2678	1339

9	0.3452E+00	1.0000	6271	1.00	0.396	41.46	0.460E-03	0.00	0.000E+00
11	0.3679E+00	1.0000	6848	1.00	0.208	42.80	0.145E-03	0.00	0.000E+00
12	0.3947E+00	1.0000	8023	1.00	0.440	44.34	0.584E-03	0.00	0.000E+00
13	0.4211E+00	1.0000	8870	1.00	0.344	45.80	0.703E-04	0.00	0.000E+00
15	0.4509E+00	1.0000	9382	1.00	0.215	47.40	0.115E-02	0.00	0.000E+00
15	0.4827E+00	1.0000	10206	1.00	0.277	49.05	0.857E-03	0.00	0.000E+00
17	0.5144E+00	1.0000	10993	1.00	0.294	50.64	0.679E-03	0.00	0.000E+00
17	0.5475E+00	1.0000	11865	1.00	0.450	52.25	0.235E-03	0.00	0.000E+00
19	0.5906E+00	1.0000	12819	1.00	0.448	54.28	0.217E-03	0.00	0.000E+00
21	0.6278E+00	1.0000	13405	1.00	0.447	55.97	0.463E-03	0.00	0.000E+00
21	0.6703E+00	1.0000	14337	1.00	0.495	57.85	0.821E-03	0.00	0.000E+00
22	0.7190E+00	1.0000	14694	1.00	0.213	59.93	0.619E-02	0.00	0.000E+00
23	0.7708E+00	1.0000	15834	1.00	0.501	62.07	0.927E-03	0.00	0.000E+00
24	0.8167E+00	1.0000	16057	1.00	0.226	63.92	0.110E-01	0.00	0.000E+00

25	0.8656E+00	1.0000	16849	1.00	0.302	65.83	0.538E-03	0.00	0.000E+00
27	0.9244E+00	1.0000	17552	1.00	0.498	68.05	0.156E-03	0.00	0.000E+00
27	0.9732E+00	1.0000	18006	1.00	0.455	69.85	0.135E-02	0.00	0.000E+00
27	0.1026E+01	1.0000	18518	1.00	0.211	71.75	0.436E-02	0.00	0.000E+00
29	0.1103E+01	1.0000	19023	1.00	0.457	74.44	0.312E-03	0.00	0.000E+00
29	0.1176E+01	1.0000	19663	1.00	0.213	76.94	0.154E-01	0.00	0.000E+00
30	0.1267E+01	1.0000	20050	1.00	0.338	79.91	0.891E-02	0.00	0.000E+00
31	0.1351E+01	1.0000	20784	1.00	0.504	82.59	0.278E-03	0.00	0.000E+00
31	0.1447E+01	1.0000	21022	1.00	0.467	85.58	0.282E-03	0.00	0.000E+00
32	0.1563E+01	1.0000	21413	1.00	0.201	89.11	0.457E-01	0.00	0.000E+00
33	0.1655E+01	1.0000	22002	1.00	0.263	91.79	0.239E-02	0.00	0.000E+00
33	0.1756E+01	1.0000	22371	1.00	0.463	94.67	0.897E-02	0.00	0.000E+00
33	0.1856E+01	1.0000	22544	1.00	0.339	97.48	0.903E-02	0.00	0.000E+00
35	0.1974E+01	1.0000	22874	1.00	0.455	100.71	0.411E-03	0.00	0.000E+00
35	0.2113E+01	1.0000	23331	1.00	0.521	104.39	0.832E-02	0.00	0.000E+00
35	0.2225E+01	1.0000	23598	1.00	0.203	107.48	0.297E-01	0.00	0.000E+00
35	0.2343E+01	1.0000	23796	1.00	0.527	110.48	0.137E-02	0.00	0.000E+00
36	0.2564E+01	1.0000	24091	1.00	0.439	115.99	0.130E-01	0.00	0.000E+00
37	0.2697E+01	1.0000	24222	1.00	0.431	119.42	0.103E-01	0.00	0.000E+00
37	0.2889E+01	1.0000	24527	1.00	0.499	124.06	0.151E-01	0.00	0.000E+00
37	0.3035E+01	1.0000	24701	1.00	0.483	127.71	0.134E-01	0.00	0.000E+00
37	0.3226E+01	1.0000	24832	1.00	0.137	132.52	0.275E-01	0.00	0.000E+00
37	0.3392E+01	1.0000	24936	1.00	0.450	136.53	0.705E-02	0.00	0.000E+00
37	0.3602E+01	1.0000	25083	1.00	0.487	141.43	0.178E-01	0.00	0.000E+00
37	0.3773E+01	1.0000	25220	1.00	0.243	145.97	0.104E-02	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 3.9745 CRACK DEPTH = 0.0500 TOTAL CYCLES = 25325

NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)

CPU TIME = 9.2 SECONDS

****

SAMPLE 9: Center-Crack Tension under NFOPT = 9 Option

SPECTRUM FILE = snfopt9 TIME LIMIT = 200.0 SECONDS

MATERIAL PROPERTIES: 2024-T3
YIELD STRESS = 0.5200E+02 ULTIMATE STRENGTH = 0.7200E+02
ELASTIC MODULUS = 0.1040E+05

PLANE STRESS SOLUTION: CONSTRAINT FACTOR = 0.100E+01
BETA = 0.100E+01

DKEFF IS ELASTIC:
CRACK GROWTH CONSTANTS:
C1 = 0.2870E-08 C2 = 4.070 C3 = 0.00 C4 = 0.00 C5 = 0.999E+03
FRACTURE TOUGHNESS PROPERTIES: KF = 0.400E+03 M = 1.00

CENTER CRACK TENSION: NTYP = 1
SPECIMEN WIDTH = 0.120E+02 THICKNESS = 0.500E-01
INITIAL CRACK LENGTH (CI) = 0.20000E+00 INITIAL CRACK DEPTH = 0.50000E-01
NOTCH LENGTH (CN) = 0.10000E+00 NOTCH DEPTH = 0.50000E-01
NOTCH HEIGHT = 0.000E+00 ELEMENTS ON STARTER NOTCH (NS) = 1
FINAL CRACK LENGTH (CF) REQUESTED = 0.12000E+02

PROGRAM OPTIONS: LFAST = 0 KOPEN = 1 KCONST = 0 INVERT = 0 LSTEP = 1
ERR = 0.124E+01 PDC = 0.20 NMAX =1000 NIPT = 3000 NPRT =-20 NDKE = 1
DCPR = 0.400E-01

PRECRACKING FROM STARTER NOTCH:
MAX STRESS = 0.2000E+02 MIN STRESS = 0.2000E+01

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKEC	DC/DN	DKEA	DA/DN
0	0.1400E+00	1.0000	6572	1.00	0.492	6.72	0.668E-05	0.00	0.000E+00
0	0.1800E+00	1.0000	11245	1.00	0.495	7.58	0.109E-04	0.00	0.000E+00

BLOCK (OR FLIGHT) LOADING: NFOPT = 9 LPRINT = 1 MAXLPR = 5
TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED = 22
NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) = 22

SPECTRUM LOAD SEQUENCE (NFOPT = 9): MAX STRESS = 0.3500E+02

NOTE: KO/KMAX AND SIF BASED ON HIGHEST AND LOWEST APPLIED STRESS IN SEQUENCE
FLIGHT-BY-FLIGHT SPECTRUM

FLIGHT	POINTS	CYCLES
1	104	52
2	138	69
3	104	52
4	104	52
5	18	9
6	110	55
7	160	80

BLOCK	C	A/T	CYCLES	ALP	KO/KMAX	DKEC	DC/DN	DKEA	DA/DN
22	0.2400E+00	1.0000	1281	1.00	0.097	15.41	0.196E-03	0.00	0.000E+00
53	0.2800E+00	1.0000	3215	1.00	0.259	16.40	0.253E-03	0.00	0.000E+00
87	0.3200E+00	1.0000	5281	1.00	0.427	11.74	0.647E-04	0.00	0.000E+00
109	0.3600E+00	1.0000	6661	1.00	0.432	15.85	0.220E-03	0.00	0.000E+00
132	0.4000E+00	1.0000	8053	1.00	0.226	10.35	0.388E-04	0.00	0.000E+00
152	0.4400E+00	1.0000	9276	1.00	0.440	17.65	0.341E-03	0.00	0.000E+00
167	0.4800E+00	1.0000	10183	1.00	0.277	22.14	0.857E-03	0.00	0.000E+00
184	0.5200E+00	1.0000	11205	1.00	0.446	16.26	0.244E-03	0.00	0.000E+00
200	0.5600E+00	1.0000	12162	1.00	0.451	18.87	0.447E-03	0.00	0.000E+00
212	0.6000E+00	1.0000	12918	1.00	0.449	16.16	0.238E-03	0.00	0.000E+00
221	0.6400E+00	1.0000	13489	1.00	0.303	24.33	0.126E-02	0.00	0.000E+00
236	0.6800E+00	1.0000	14365	1.00	0.288	29.85	0.289E-02	0.00	0.000E+00
242	0.7200E+00	1.0000	14716	1.00	0.439	20.46	0.622E-03	0.00	0.000E+00
255	0.7600E+00	1.0000	15512	1.00	0.501	22.56	0.927E-03	0.00	0.000E+00
264	0.8000E+00	1.0000	16055	1.00	0.226	41.43	0.110E-01	0.00	0.000E+00
273	0.8400E+00	1.0000	16560	1.00	0.482	11.99	0.708E-04	0.00	0.000E+00
279	0.8800E+00	1.0000	16972	1.00	0.447	28.07	0.226E-02	0.00	0.000E+00
287	0.9200E+00	1.0000	17472	1.00	0.498	14.57	0.156E-03	0.00	0.000E+00
294	0.9600E+00	1.0000	17853	1.00	0.455	24.76	0.135E-02	0.00	0.000E+00

299	0.1000E+01	1.0000	18216	1.00	0.499	25.58	0.155E-02	0.00	0.000E+00
306	0.1040E+01	1.0000	18602	1.00	0.436	22.18	0.865E-03	0.00	0.000E+00
308	0.1080E+01	1.0000	18754	1.00	0.457	17.27	0.312E-03	0.00	0.000E+00
315	0.1120E+01	1.0000	19077	1.00	0.504	26.86	0.189E-02	0.00	0.000E+00
323	0.1160E+01	1.0000	19661	1.00	0.213	44.96	0.154E-01	0.00	0.000E+00
326	0.1200E+01	1.0000	19838	1.00	0.446	29.27	0.268E-02	0.00	0.000E+00
329	0.1240E+01	1.0000	20026	1.00	0.434	20.46	0.623E-03	0.00	0.000E+00
331	0.1280E+01	1.0000	20146	1.00	0.462	21.61	0.778E-03	0.00	0.000E+00
335	0.1320E+01	1.0000	20372	1.00	0.504	16.78	0.278E-03	0.00	0.000E+00
342	0.1360E+01	1.0000	20785	1.00	0.281	52.83	0.297E-01	0.00	0.000E+00
342	0.1400E+01	1.0000	20866	1.00	0.326	24.51	0.130E-02	0.00	0.000E+00
345	0.1440E+01	1.0000	21005	1.00	0.467	16.84	0.282E-03	0.00	0.000E+00
347	0.1480E+01	1.0000	21124	1.00	0.498	24.81	0.137E-02	0.00	0.000E+00
352	0.1526E+01	1.0000	21412	1.00	0.201	58.73	0.457E-01	0.00	0.000E+00
353	0.1572E+01	1.0000	21501	1.00	0.406	20.09	0.579E-03	0.00	0.000E+00
360	0.1617E+01	1.0000	21857	1.00	0.496	35.39	0.581E-02	0.00	0.000E+00
363	0.1665E+01	1.0000	22069	1.00	0.499	19.61	0.525E-03	0.00	0.000E+00
367	0.1713E+01	1.0000	22325	1.00	0.224	22.55	0.925E-03	0.00	0.000E+00
368	0.1760E+01	1.0000	22377	1.00	0.409	34.01	0.493E-02	0.00	0.000E+00
370	0.1808E+01	1.0000	22499	1.00	0.492	34.26	0.509E-02	0.00	0.000E+00
371	0.1856E+01	1.0000	22543	1.00	0.339	39.45	0.903E-02	0.00	0.000E+00
373	0.1903E+01	1.0000	22704	1.00	0.474	39.12	0.875E-02	0.00	0.000E+00
375	0.1964E+01	1.0000	22847	1.00	0.455	18.47	0.411E-03	0.00	0.000E+00
378	0.2026E+01	1.0000	22976	1.00	0.526	21.00	0.693E-03	0.00	0.000E+00
382	0.2087E+01	1.0000	23231	1.00	0.521	38.64	0.832E-02	0.00	0.000E+00
385	0.2152E+01	1.0000	23423	1.00	0.491	22.83	0.975E-03	0.00	0.000E+00
388	0.2217E+01	1.0000	23597	1.00	0.203	52.85	0.297E-01	0.00	0.000E+00
390	0.2283E+01	1.0000	23694	1.00	0.396	37.34	0.722E-02	0.00	0.000E+00
391	0.2348E+01	1.0000	23801	1.00	0.492	41.78	0.114E-01	0.00	0.000E+00
393	0.2418E+01	1.0000	23878	1.00	0.301	63.65	0.636E-01	0.00	0.000E+00
393	0.2488E+01	1.0000	23907	1.00	0.439	43.12	0.130E-01	0.00	0.000E+00
396	0.2574E+01	1.0000	24093	1.00	0.152	34.85	0.544E-02	0.00	0.000E+00
397	0.2660E+01	1.0000	24157	1.00	0.431	40.75	0.103E-01	0.00	0.000E+00
400	0.2746E+01	1.0000	24312	1.00	0.523	28.83	0.253E-02	0.00	0.000E+00
403	0.2832E+01	1.0000	24461	1.00	0.499	44.71	0.151E-01	0.00	0.000E+00
404	0.2924E+01	1.0000	24544	1.00	0.467	21.56	0.773E-03	0.00	0.000E+00
406	0.3016E+01	1.0000	24680	1.00	0.483	43.44	0.134E-01	0.00	0.000E+00
407	0.3107E+01	1.0000	24757	1.00	0.526	24.65	0.133E-02	0.00	0.000E+00
408	0.3210E+01	1.0000	24830	1.00	0.137	51.83	0.275E-01	0.00	0.000E+00
409	0.3312E+01	1.0000	24891	1.00	0.431	48.44	0.209E-01	0.00	0.000E+00
410	0.3414E+01	1.0000	24957	1.00	0.542	52.41	0.290E-01	0.00	0.000E+00
412	0.3517E+01	1.0000	25033	1.00	0.487	46.52	0.178E-01	0.00	0.000E+00
412	0.3619E+01	1.0000	25087	1.00	0.386	47.46	0.193E-01	0.00	0.000E+00
413	0.3722E+01	1.0000	25169	1.00	0.467	46.63	0.180E-01	0.00	0.000E+00

SPECIMEN FAILED:

CRACK LENGTH = 3.9745 CRACK DEPTH = 0.0500 TOTAL CYCLES = 25325

NFCODE = 4: KMAX > KIE (ELASTIC SIF AT FAILURE)

CPU TIME = 9.1 SECONDS

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SAMPLE 10: Threshold Test (KTH = 3  Option)

SPECTRUM FILE = cstamp          TIME LIMIT =  200.0 SECONDS

MATERIAL PROPERTIES:   2618-T651
YIELD STRESS = 0.6000E+02     ULTIMATE STRENGTH = 0.6000E+02
ELASTIC MODULUS = 0.1000E+05

PLANE STRESS SOLUTION:     CONSTRAINT FACTOR = 0.100E+01
                                        BETA = 0.100E+01

DKEFF IS ELASTIC:
     CRACK GROWTH CONSTANTS:
     C1 =  0.4000E-08   C2 = 3.500   C3 =  0.00   C4 =  0.00   C5 = 0.999E+03
     FRACTURE TOUGHNESS PROPERTIES:    KF = 0.800E+02     M = 0.00


CENTER CRACK TENSION: NTYP = 1
     SPECIMEN WIDTH = 0.120E+02     THICKNESS = 0.100E+00
     INITIAL CRACK LENGTH (CI) = 0.45000E+00   INITIAL CRACK DEPTH = 0.10000E+00
     NOTCH LENGTH (CN) = 0.40000E+00    NOTCH DEPTH = 0.10000E+00
     NOTCH HEIGHT = 0.000E+00    ELEMENTS ON STARTER NOTCH (NS) = 1
     FINAL CRACK LENGTH (CF) REQUESTED =  0.70000E+00

PROGRAM OPTIONS:  LFAST = 0   KOPEN = 1   KCONST = 0   INVERT = 0   LSTEP = 1
  ERR = 0.120E+01  PDC = 0.20  NMAX =1000  NIPT = 3000  NPRT = 30  NDKE = 0

  PRECRACKING FROM STARTER NOTCH:
  MAX STRESS = 0.7000E+01     MIN STRESS =  0.7000E+00

 BLOCK     C         A/T    CYCLES  ALP  KO/KMAX  DKC   DC/DN      DKA   DA/DN

    0  0.4104E+00 1.0000    16270  1.00  0.511    7.16 0.462E-06   0.00 0.000E+00
    0  0.4210E+00 1.0000    39947  1.00  0.522    7.25 0.447E-06   0.00 0.000E+00
    0  0.4319E+00 1.0000    64040  1.00  0.524    7.34 0.461E-06   0.00 0.000E+00
    0  0.4431E+00 1.0000    87907  1.00  0.525    7.44 0.478E-06   0.00 0.000E+00

  BLOCK (OR FLIGHT) LOADING:  NFOPT = 0     LPRINT = 0     MAXLPR =    0
     TOTAL NUMBER OF BLOCKS (OR) FLIGHTS TO BE REPEATED =    1
     NUMBER OF DIFFERENT BLOCKS (OR FLIGHTS) =    1

    BLOCK  1     NUMBER OF STRESS LEVELS =   1    NSQ =   1     SCALE =   1.00
               LEVEL     SMAX            SMIN            CYCLES
                 1     0.7000E+01     0.7000E+00          1000

  LOAD REDUCTION SCHEME:   METHOD  3
    SMAXTH = 0.700E+01    RTH = 0.100E+00    CONST = 0.780E-02

    NOTE: KO/KMAX AND SIF BASED ON APPLIED STRESS, SMAX, AND R

 BLOCK     C         A/T    CYCLES  ALP  KO/KMAX  DKC   DC/DN      DKA   DA/DN

          SMAX =   7.00
    2  0.4503E+00 1.0000     1585  1.00  0.635    7.50 0.196E-06   0.00 0.000E+00
          SMAX =   7.00
   20  0.4585E+00 1.0000    19363  1.00  0.530    7.57 0.213E-06   0.00 0.000E+00
```

	SMAX =	6.30							
25	0.4590E+00	1.0000	24034	1.00	0.696	6.81	0.742E-07	0.00	0.000E+00
	SMAX =	6.30							
40	0.4600E+00	1.0000	39307	1.00	0.665	6.82	0.104E-06	0.00	0.000E+00
	SMAX =	6.30							
50	0.4621E+00	1.0000	49493	1.00	0.568	6.84	0.256E-06	0.00	0.000E+00
	SMAX =	6.30							
65	0.4662E+00	1.0000	64862	1.00	0.543	6.87	0.133E-06	0.00	0.000E+00
	SMAX =	5.67							
72	0.4666E+00	1.0000	71581	1.00	0.717	6.18	0.412E-07	0.00	0.000E+00
	SMAX =	5.67							
94	0.4675E+00	1.0000	93009	1.00	0.674	6.19	0.673E-07	0.00	0.000E+00
	SMAX =	5.67							
107	0.4692E+00	1.0000	106034	1.00	0.578	6.20	0.167E-06	0.00	0.000E+00
	SMAX =	5.67							
124	0.4726E+00	1.0000	123399	1.00	0.551	6.22	0.211E-06	0.00	0.000E+00
	SMAX =	5.67							
129	0.4736E+00	1.0000	128914	1.00	0.548	6.23	0.907E-07	0.00	0.000E+00
	SMAX =	5.10							
138	0.4740E+00	1.0000	137082	1.00	0.721	5.61	0.276E-07	0.00	0.000E+00
	SMAX =	5.10							
163	0.4747E+00	1.0000	162994	1.00	0.676	5.61	0.469E-07	0.00	0.000E+00
	SMAX =	5.10							
179	0.4761E+00	1.0000	178288	1.00	0.579	5.62	0.118E-06	0.00	0.000E+00
	SMAX =	5.10							
199	0.4789E+00	1.0000	198695	1.00	0.553	5.64	0.147E-06	0.00	0.000E+00
	SMAX =	5.10							
218	0.4815E+00	1.0000	217604	1.00	0.548	5.65	0.644E-07	0.00	0.000E+00
	SMAX =	4.59							
227	0.4818E+00	1.0000	226797	1.00	0.719	5.09	0.203E-07	0.00	0.000E+00
	SMAX =	4.59							
256	0.4823E+00	1.0000	255270	1.00	0.675	5.09	0.339E-07	0.00	0.000E+00
	SMAX =	4.59							
273	0.4835E+00	1.0000	272835	1.00	0.580	5.10	0.829E-07	0.00	0.000E+00
	SMAX =	4.59							
297	0.4858E+00	1.0000	296669	1.00	0.554	5.11	0.103E-06	0.00	0.000E+00
	SMAX =	4.59							
330	0.4892E+00	1.0000	329550	1.00	0.544	5.13	0.477E-07	0.00	0.000E+00
	SMAX =	4.13							
341	0.4895E+00	1.0000	340166	1.00	0.719	4.62	0.144E-07	0.00	0.000E+00
	SMAX =	4.13							
376	0.4899E+00	1.0000	375164	1.00	0.680	4.62	0.227E-07	0.00	0.000E+00
	SMAX =	4.13							
396	0.4909E+00	1.0000	395696	1.00	0.580	4.62	0.589E-07	0.00	0.000E+00
	SMAX =	4.13							
424	0.4927E+00	1.0000	423217	1.00	0.554	4.63	0.736E-07	0.00	0.000E+00
	SMAX =	4.13							
473	0.4965E+00	1.0000	472433	1.00	0.545	4.65	0.799E-07	0.00	0.000E+00
	SMAX =	4.13							
481	0.4970E+00	1.0000	480256	1.00	0.544	4.65	0.337E-07	0.00	0.000E+00
	SMAX =	3.72							
493	0.4972E+00	1.0000	492264	1.00	0.717	4.19	0.105E-07	0.00	0.000E+00
	SMAX =	3.72							
532	0.4976E+00	1.0000	531297	1.00	0.676	4.19	0.169E-07	0.00	0.000E+00
	SMAX =	3.72							
556	0.4983E+00	1.0000	555171	1.00	0.580	4.19	0.420E-07	0.00	0.000E+00
	SMAX =	3.72							
588	0.4999E+00	1.0000	587017	1.00	0.555	4.20	0.517E-07	0.00	0.000E+00

	SMAX =	3.72							
644	0.5030E+00	1.0000	643967	1.00	0.545	4.21	0.563E-07	0.00	0.000E+00
	SMAX =	3.72							
676	0.5047E+00	1.0000	675831	1.00	0.543	4.22	0.242E-07	0.00	0.000E+00
	SMAX =	3.35							
690	0.5049E+00	1.0000	689644	1.00	0.717	3.80	0.749E-08	0.00	0.000E+00
	SMAX =	3.35							
735	0.5052E+00	1.0000	734721	1.00	0.676	3.80	0.120E-07	0.00	0.000E+00
	SMAX =	3.35							
763	0.5058E+00	1.0000	762195	1.00	0.579	3.80	0.300E-07	0.00	0.000E+00
	SMAX =	3.35							
800	0.5071E+00	1.0000	799121	1.00	0.555	3.81	0.367E-07	0.00	0.000E+00
	SMAX =	3.35							
866	0.5097E+00	1.0000	865380	1.00	0.547	3.82	0.394E-07	0.00	0.000E+00
	SMAX =	3.35							
939	0.5125E+00	1.0000	938977	1.00	0.543	3.83	0.172E-07	0.00	0.000E+00
	SMAX =	3.01							
956	0.5127E+00	1.0000	955047	1.00	0.717	3.45	0.530E-08	0.00	0.000E+00
	SMAX =	3.01							
1007	0.5129E+00	1.0000	1006985	1.00	0.676	3.45	0.854E-08	0.00	0.000E+00
	SMAX =	3.01							
1039	0.5134E+00	1.0000	1038452	1.00	0.578	3.45	0.214E-07	0.00	0.000E+00
	SMAX =	3.01							
1082	0.5145E+00	1.0000	1081417	1.00	0.556	3.45	0.258E-07	0.00	0.000E+00
	SMAX =	3.01							
1159	0.5166E+00	1.0000	1158656	1.00	0.548	3.46	0.277E-07	0.00	0.000E+00
	SMAX =	3.01							
1294	0.5203E+00	1.0000	1293331	1.00	0.543	3.47	0.122E-07	0.00	0.000E+00
	SMAX =	2.71							
1312	0.5204E+00	1.0000	1311956	1.00	0.717	3.12	0.375E-08	0.00	0.000E+00
	SMAX =	2.71							
1374	0.5206E+00	1.0000	1373319	1.00	0.677	3.13	0.596E-08	0.00	0.000E+00
	SMAX =	2.71							
1410	0.5211E+00	1.0000	1409886	1.00	0.581	3.13	0.149E-07	0.00	0.000E+00
	SMAX =	2.71							
1460	0.5219E+00	1.0000	1459620	1.00	0.556	3.13	0.182E-07	0.00	0.000E+00
	SMAX =	2.71							
1550	0.5236E+00	1.0000	1549173	1.00	0.547	3.13	0.197E-07	0.00	0.000E+00
	SMAX =	2.71							
1722	0.5271E+00	1.0000	1721103	1.00	0.545	3.14	0.203E-07	0.00	0.000E+00
	SMAX =	2.71							
1772	0.5281E+00	1.0000	1771787	1.00	0.545	3.15	0.853E-08	0.00	0.000E+00
	SMAX =	2.44							
1794	0.5282E+00	1.0000	1793724	1.00	0.719	2.83	0.261E-08	0.00	0.000E+00
	SMAX =	2.44							
1865	0.5283E+00	1.0000	1864692	1.00	0.675	2.83	0.433E-08	0.00	0.000E+00
	SMAX =	2.44							
1908	0.5287E+00	1.0000	1907194	1.00	0.581	2.83	0.105E-07	0.00	0.000E+00
	SMAX =	2.44							
1966	0.5294E+00	1.0000	1965254	1.00	0.558	2.84	0.128E-07	0.00	0.000E+00
	SMAX =	2.44							
2071	0.5308E+00	1.0000	2070353	1.00	0.549	2.84	0.137E-07	0.00	0.000E+00
	SMAX =	2.44							
2273	0.5336E+00	1.0000	2272061	1.00	0.548	2.85	0.140E-07	0.00	0.000E+00
	SMAX =	2.44							
2435	0.5359E+00	1.0000	2434246	1.00	0.545	2.85	0.604E-08	0.00	0.000E+00
	SMAX =	2.20							
2461	0.5360E+00	1.0000	2460219	1.00	0.721	2.57	0.181E-08	0.00	0.000E+00

SMAX = 2.20
2546 0.5361E+00 1.0000 2545561 1.00 0.679 2.57 0.296E-08 0.00 0.000E+00
SMAX = 2.20
2596 0.5364E+00 1.0000 2595533 1.00 0.580 2.57 0.754E-08 0.00 0.000E+00
SMAX = 2.20
2664 0.5370E+00 1.0000 2663069 1.00 0.558 2.57 0.907E-08 0.00 0.000E+00
SMAX = 2.20
2786 0.5381E+00 1.0000 2785229 1.00 0.551 2.57 0.960E-08 0.00 0.000E+00
SMAX = 2.20
3022 0.5404E+00 1.0000 3021697 1.00 0.549 2.58 0.983E-08 0.00 0.000E+00
SMAX = 2.20
3348 0.5436E+00 1.0000 3347553 1.00 0.546 2.59 0.425E-08 0.00 0.000E+00
SMAX = 1.98
3378 0.5437E+00 1.0000 3377740 1.00 0.721 2.33 0.128E-08 0.00 0.000E+00
SMAX = 1.98
3476 0.5438E+00 1.0000 3475028 1.00 0.676 2.33 0.215E-08 0.00 0.000E+00
SMAX = 1.98
3533 0.5441E+00 1.0000 3532265 1.00 0.581 2.33 0.530E-08 0.00 0.000E+00
SMAX = 1.98
3611 0.5445E+00 1.0000 3610661 1.00 0.557 2.33 0.647E-08 0.00 0.000E+00
SMAX = 1.98
3752 0.5455E+00 1.0000 3751033 1.00 0.548 2.33 0.693E-08 0.00 0.000E+00
SMAX = 1.98
4024 0.5474E+00 1.0000 4023910 1.00 0.548 2.34 0.702E-08 0.00 0.000E+00
SMAX = 1.98
4565 0.5512E+00 1.0000 4564451 1.00 0.546 2.34 0.717E-08 0.00 0.000E+00
SMAX = 1.98
4600 0.5514E+00 1.0000 4599161 1.00 0.547 2.34 0.299E-08 0.00 0.000E+00
SMAX = 1.78
4635 0.5515E+00 1.0000 4634641 1.00 0.722 2.11 0.890E-09 0.00 0.000E+00
SMAX = 1.78
4751 0.5516E+00 1.0000 4750169 1.00 0.678 2.11 0.150E-08 0.00 0.000E+00
SMAX = 1.78
4818 0.5518E+00 1.0000 4817320 1.00 0.583 2.11 0.371E-08 0.00 0.000E+00
SMAX = 1.78
4909 0.5522E+00 1.0000 4908497 1.00 0.558 2.11 0.455E-08 0.00 0.000E+00
SMAX = 1.78
5073 0.5529E+00 1.0000 5072714 1.00 0.550 2.11 0.485E-08 0.00 0.000E+00
SMAX = 1.78
5393 0.5545E+00 1.0000 5392968 1.00 0.550 2.12 0.488E-08 0.00 0.000E+00
SMAX = 1.78
6029 0.5576E+00 1.0000 6028876 1.00 0.549 2.12 0.498E-08 0.00 0.000E+00
SMAX = 1.78
6357 0.5592E+00 1.0000 6356577 1.00 0.548 2.13 0.209E-08 0.00 0.000E+00
SMAX = 1.60
6399 0.5593E+00 1.0000 6398688 1.00 0.725 1.91 0.614E-09 0.00 0.000E+00
SMAX = 1.60
6536 0.5594E+00 1.0000 6535808 1.00 0.679 1.91 0.105E-08 0.00 0.000E+00
SMAX = 1.60
6615 0.5595E+00 1.0000 6614322 1.00 0.584 1.91 0.261E-08 0.00 0.000E+00
SMAX = 1.60
6722 0.5598E+00 1.0000 6721288 1.00 0.558 1.91 0.321E-08 0.00 0.000E+00
SMAX = 1.60
6914 0.5605E+00 1.0000 6913013 1.00 0.551 1.92 0.340E-08 0.00 0.000E+00
SMAX = 1.60
7290 0.5618E+00 1.0000 7289119 1.00 0.551 1.92 0.343E-08 0.00 0.000E+00
SMAX = 1.60
8037 0.5643E+00 1.0000 8036807 1.00 0.551 1.92 0.346E-08 0.00 0.000E+00

```
          SMAX =    1.60
8817   0.5670E+00 1.0000 8816028  1.00  0.550   1.93 0.146E-08   0.00 0.000E+00
          SMAX =    1.44
8867   0.5671E+00 1.0000 8866675  1.00  0.728   1.73 0.417E-09   0.00 0.000E+00
          SMAX =    1.44
9035   0.5671E+00 1.0000 9034217  1.00  0.686   1.73 0.692E-09   0.00 0.000E+00
          SMAX =    1.44
9127   0.5673E+00 1.0000 9126504  1.00  0.584   1.73 0.184E-08   0.00 0.000E+00
          SMAX =    1.44
9252   0.5675E+00 1.0000 9251880  1.00  0.560   1.73 0.224E-08   0.00 0.000E+00
          SMAX =    1.44
9478   0.5680E+00 1.0000 9477158  1.00  0.553   1.74 0.237E-08   0.00 0.000E+00
          SMAX =    1.44
9921   0.5691E+00 1.0000 9920340  1.00  0.554   1.74 0.237E-08   0.00 0.000E+00

    NUMBER OF CYCLES EXCEED 10 MILLION

  CPU TIME =    42.1   SECONDS
```

VII. USER GUIDE FOR EFFECTIVE STRESS-INTENSITY FACTOR PROGRAM

A. Introduction

A computer program DKEFF (dkeff.for) was also developed to help the user determine the ΔK_{eff} (or $\Delta \bar{K}_{eff}$) against crack-growth rate relations for a given material and thickness using either center-crack or compact specimens. The program is a FORTRAN code designed to be executed interactively on a personal computer. A line-by-line explanation of the crack-growth rate input data file and interactive terminal input is presented herein. The parameters used in the input data file and for terminal input are defined and explained in Sections VII.B and VII.C, respectively. The input data are in free format unless otherwise stated. Several data sets can be analyzed for the same specimen type during each computer run by placing input data sets in series. An example input and output data file are given in Section VII.D. A list of error messages are also given and discussed.

B. Crack-Growth Rate Analysis (Input Data) File

1. Data Set Title

```
READ  TITLE(20)
FORMAT (20A4)
```

Any 80-character title describing the data set.

2. Material

```
READ  MAT
FORMAT (20A4)
```

Any 80-character description of the material.

3. Specimen Type and System of Units Option

```
READ  NTYP, LUNIT
```

NTYP = Specimen Type
= 1 Center-crack tension specimen
= 2 Compact tension specimen

LUNIT = 0 Input and output data have same units
= 1 Input in English and output in SI units
= 2 Input in SI and output in English units

All units used for input data must be consistent. For example,

	SI Units	U.S. Customary
Length:	m	in.
Stress:	MPa	ksi
ΔK (or K):	MPa-m$^{1/2}$	ksi-in$^{1/2}$
dc/dN (or da/dN):	m/cycle	in/cycle

4. Material Tensile Yielding Properties

READ SYIELD, SULT, E, NEP, NALP, ALP

SYIELD = Yield stress (0.2 percent offset)

SULT = Ultimate tensile strength

E = Elastic modulus

NEP = 0 Effective stress-intensity factor is elastic

= 1 Effective stress-intensity factor is modified for yielding at the crack tip. One-quarter of cyclic plastic zone is added to crack length (see eqn.(11)). (Note: The plasticity corrected stress-intensity factor in FASTRAN-II is different than that used in references 5 and 8. A closure corrected "cyclic" plastic zone size is used instead of the maximum plastic zone size.)

= 2 Effective stress-intensity factor is modified for yielding at the crack tip. One-quarter of monotonic plastic zone is added to crack length.

NALP = 0 Constraint factor (ALP) is constant as input

= 1 Constraint factor is variable (ALP is computed by the program, see Section III.B.8).

FASTRAN-II must use the crack-growth rate relation, ΔK_{eff} (or $\Delta\bar{K}_{eff}$) against dc/dN or da/dN, that is obtained with the specified NALP option.

ALP = Constraint factor
= 1 Plane-stress condition
= 1.73 Irwin's plane-strain condition
= 3 Plane-strain condition

See references 3 and 9 for procedures to obtain the value of ALP for a particular material, thickness, and test condition. The flow stress, SFLOW, computed in the program is the average of the yield stress and ultimate tensile strength.

5. Crack Growth Rates at Transition (NALP = 1 option only)

READ RATE1, ALP1, RATE2, ALP2

If NALP = 0 No input is required, go to section 6.

If NALP = 1 RATE1 is the crack-growth rate near the start of transition from flat-to-slant growth (ALP = ALP1 for rates less than RATE1). RATE2 is the crack growth rate near the end of the transition from flat-to-slant growth (ALP = ALP2 for rates greater than RATE2). For rates (RATES) between RATE1 and RATE2 a linear relation is used, see equation (20).

6. Data Points, Loading and Specimen Dimensions

READ MTAB, R, SMAX, W, T

MTAB = Number of ΔK-rate data points to be analyzed

R = Stress ratio (S_{min}/S_{max})

SMAX = Remote applied stress on center-crack tension specimen or P/(WT) for compact tension specimen (P = applied load)

W = Specimen half-width for center-crack tension specimen or specimen width for compact tension specimen

T = Specimen thickness

7. Stress-Intensity Factor Range and Rates

READ DK(I), RATE(I)

DK(I) = Elastic stress-intensity factor range ($\Delta K = K_{max} - K_{min}$)

RATE(I) = Corresponding crack-growth rate (dc/dN)

Repeat step 7 MTAB times. To analyze another data set on the same specimen type (NTYP), repeat sections 6 and 7. Repeat until all data sets are input. Enter '0 0 0 0 0' at the end of the last data set to terminate analysis.

C. Interactive Input on Personal Computer (computer response is in bold letters)

1. **ENTER DATA FILE NAME :**

READ DATFILE
FORMAT(A8)

Crack-growth rate input data filename

2. **ENTER OUTPUT FILE NAME :**

READ OUTFILE
FORMAT(A8)

Output filename

3. **SHORT FILE: DKEFF-DATA ? YES= 1 NO=0**

READ NSIG

NSIG = 0 Long output file
Echos all input data and prints out effective stress-intensity factor, crack-growth rate, crack-opening stress, maximum applied stress, constraint factor and crack length.

1 Short output file
Miminal output of effective stress-intensity factor, crack-growth rate, crack-opening stress, maximum applied stress, constraint factor and crack length.

4. **DELTA-K(0) DELTA-KEFF(1) OR DELTA-KBAREFF(2) ?**

READ NDKEP

NDKEP = 0 Elastic stress-intensity factor ranges printed out
1 Effective (elastic) stress-intensity factor ranges printed out
2 Effective (elastic-plastic) stress-intensity factor ranges printed out (NEP = 1 or 2).

5. **ERROR: NEP = 0 FOR ELASTIC-PLASTIC ANALYSIS INPUT DESIRED VALUE OF NEP (0, 1, OR 2)?**

READ(5,*) NEP

For NDKEP = 2, NEP was not set to 1 or 2 in the input data file. User can override and set NEP = 0, 1 or 2. An elastic-plastic analysis will be conducted using either NEP = 1 or 2. Program will terminate if NEP is input as zero.

If NEP = 1 or 2, and NALP = 0, program goes to 6.
If NEP = 1 or 2, and NALP = 1, program goes to 7.

6. **IS VALUE OF ALP OK ? YES=1 NO=0**

READ NQ

If NQ = 0, ---- **CORRECT VALUES IN INPUT DATA FILE** ----
and program terminates.

If NQ = 1, program continues and completes the analysis.

7. **ARE RATE AND ALP VALUES OK ? YES=1 NO=0**

READ NQ

If NQ = 0, ---- **CORRECT VALUES IN INPUT DATA FILE** ----
and program terminates.

If NQ = 1, program continues and completes the analysis.

D. Example Input and Output Data Files

1. <u>Input File.</u>-An example crack-growth rate input data file is contained in the file 'ctn.dat'. The input data file was given in English units but the output is requested in SI units (LUNIT = 1). The variable constraint option (NALP = 1) was also selected. The values of RATE1 and RATE2 were selected to correspond closely with the transition region from flat-to-slant crack growth. The values of constraint have been selected by trial-and-error to correlate crack-growth rate data at differenct stress ratio (R) conditions. Two data sets on compact specimens are included, one

at a stress ratio of 0.5 and the other at R = 0.1. The input data file is as follows:

```
Compact Tension Specimens
 7075-T651
 2  1
 77.  85.  10400.  0  1  1.9
 2.0E-05  1.9  1.0E-3  1.2
 13  0.5  1.0  3.0  0.25
    4.69   2.29E-06
    4.84   2.58E-06
    5.02   2.94E-06
    5.22   3.30E-06
    5.45   3.74E-06
    5.74   4.26E-06
    6.07   4.93E-06
    6.35   5.50E-06
    6.67   6.14E-06
    7.08   6.94E-06
    7.58   8.17E-06
    7.89   9.15E-06
    8.26   1.05E-05
 12  0.1  0.7  3.0  0.25
    5.43   6.71E-07
    5.84   1.72E-06
    6.37   3.03E-06
    7.41   4.78E-06
    9.37   6.82E-06
   11.66   1.27E-05
   12.79   1.65E-05
   13.73   2.07E-05
   14.84   2.47E-05
   16.02   3.32E-05
   17.48   4.16E-05
   19.21   6.39E-05
```

2. Output File.-The data in the example input data file was given in English units and the output file is given in SI units (LUNIT = 1). The long output file option (NSIG = 0) was selected using terminal input (see VII.C.3). The long output file gives the input ΔK-rate data and information on loading and specimen dimensions. Because the compact specimen was being analyzed, a stress level (Smax') was calculated for a center-crack tension specimen that would give the same elastic stress-intensity factor as that applied to the compact specimen. This stress level is used to calculate an equivalent crack-opening stress level (So/Smax) for the compact specimen (Smax' = RSF * Smax). The corresponding output data file is as follows:

```
Compact Tension Specimens
MATERIAL PROPERTIES : 7075-T651

     COMPACT SPECIMEN

     INPUT IN ENGLISH AND OUTPUT IN SI UNITS

YIELD STRESS =  .5309E+03     ULTIMATE STRENGTH =  .5861E+03
ELASTIC MODULUS =  .7171E+05 MPa
```

PLANE-STRAIN-TO-PLANE-STRESS SOLUTION:
(ALP = ALP1 TO ALP2)
RATE1 = .5080E-06 m/cycle   ALP1 = .190E+01
RATE2 = .2540E-04 m/cycle   ALP2 = .120E+01

NTAB = 13

R = .50 Smax = .6895E+01 MPa w = .7620E-01 m t = .6350E-02 m

DELTA-K MPa-m^0.5	RATE m/cycle	RSF
.5154E+01	.5817E-07	.5426E+01
.5319E+01	.6553E-07	.5459E+01
.5517E+01	.7468E-07	.5501E+01
.5737E+01	.8382E-07	.5549E+01
.5990E+01	.9500E-07	.5607E+01
.6308E+01	.1082E-06	.5683E+01
.6671E+01	.1252E-06	.5774E+01
.6979E+01	.1397E-06	.5854E+01
.7330E+01	.1560E-06	.5948E+01
.7781E+01	.1763E-06	.6072E+01
.8330E+01	.2075E-06	.6229E+01
.8671E+01	.2324E-06	.6327E+01
.9078E+01	.2667E-06	.6447E+01

DKEFF ELASTIC:

DKEFF MPa-m^0.5	RATE m/cycle	So/Smax'	Smax' MPa	ALP	c m
.4499E+01	.5817E-07	.5636E+00	.3741E+02	.1900E+01	.2177E-01
.4640E+01	.6553E-07	.5638E+00	.3764E+02	.1900E+01	.2269E-01
.4811E+01	.7468E-07	.5640E+00	.3793E+02	.1900E+01	.2377E-01
.5000E+01	.8382E-07	.5642E+00	.3826E+02	.1900E+01	.2493E-01
.5219E+01	.9500E-07	.5644E+00	.3866E+02	.1900E+01	.2621E-01
.5495E+01	.1082E-06	.5645E+00	.3918E+02	.1900E+01	.2775E-01
.5808E+01	.1252E-06	.5647E+00	.3981E+02	.1900E+01	.2939E-01
.6075E+01	.1397E-06	.5648E+00	.4036E+02	.1900E+01	.3069E-01
.6380E+01	.1560E-06	.5648E+00	.4101E+02	.1900E+01	.3209E-01
.6771E+01	.1763E-06	.5649E+00	.4187E+02	.1900E+01	.3375E-01
.7246E+01	.2075E-06	.5651E+00	.4295E+02	.1900E+01	.3558E-01
.7540E+01	.2324E-06	.5652E+00	.4363E+02	.1900E+01	.3663E-01
.7889E+01	.2667E-06	.5655E+00	.4445E+02	.1900E+01	.3779E-01

NTAB = 12

R = .10 Smax = .4826E+01 MPa w = .7620E-01 m t = .6350E-02 m

DELTA-K MPa-m^0.5	RATE m/cycle	RSF
.5968E+01	.1704E-07	.5349E+01
.6418E+01	.4369E-07	.5414E+01
.7001E+01	.7696E-07	.5509E+01
.8144E+01	.1214E-06	.5721E+01
.1030E+02	.1732E-06	.6183E+01
.1281E+02	.3226E-06	.6773E+01
.1406E+02	.4191E-06	.7070E+01
.1509E+02	.5258E-06	.7318E+01

.1631E+02	.6274E-06	.7610E+01
.1761E+02	.8433E-06	.7918E+01
.1921E+02	.1057E-05	.8294E+01
.2111E+02	.1623E-05	.8734E+01

DKEFF ELASTIC:

DKEFF MPa-m^0.5	RATE m/cycle	So/Smax'	Smax' MPa	ALP	c m
.4145E+01	.1704E-07	.3748E+00	.2582E+02	.1900E+01	.1935E-01
.4438E+01	.4369E-07	.3777E+00	.2613E+02	.1900E+01	.2143E-01
.4826E+01	.7696E-07	.3796E+00	.2659E+02	.1900E+01	.2398E-01
.5606E+01	.1214E-06	.3804E+00	.2761E+02	.1900E+01	.2846E-01
.7097E+01	.1732E-06	.3798E+00	.2984E+02	.1900E+01	.3508E-01
.8817E+01	.3226E-06	.3807E+00	.3269E+02	.1900E+01	.4052E-01
.9665E+01	.4191E-06	.3812E+00	.3412E+02	.1900E+01	.4259E-01
.1035E+02	.5258E-06	.3825E+00	.3532E+02	.1894E+01	.4409E-01
.1110E+02	.6274E-06	.3872E+00	.3673E+02	.1862E+01	.4564E-01
.1181E+02	.8433E-06	.3961E+00	.3821E+02	.1809E+01	.4710E-01
.1275E+02	.1057E-05	.4025E+00	.4003E+02	.1769E+01	.4866E-01
.1369E+02	.1623E-05	.4164E+00	.4215E+02	.1692E+01	.5025E-01

E. Error Messages

The program DKEFF (dkeff.for) has several error checks on the input data and execution errors that may be helpful to the user. These error messages are listed and some are briefly discussed.

1. INPUT ERROR: NEP OUT OF RANGE--NEP = 'value'
   NEP must be either 0, 1 or 2.

2. INPUT ERROR: NTYP MUST BE 1 OR 2
   Only center-crack tension and compact specimens are used to obtain baseline crack-growth rate data.

3. INPUT ERROR: MTAB= 'value' > MAXN= 200'
   Maximum number of ΔK and dc/dN pairs are limited to MAXN. MAXN is currently set at 200.

4. INPUT ERROR: CHECK LUNIT VALUE

5. INPUT ERROR: RATE1 MUST BE LESS THAN RATE2 AND
   ALP1 MUST BE GREATER THAN ALP2

6. CAUTION: SMAX > 0.6 SFLOW SHOULD RUN FASTRAN-II
   TO OBTAIN CRACK-OPENING STRESSES

7. WARNING: SMAX > 0.8 SFLOW !!! MUST RUN FASTRAN-II
   TO OBTAIN CRACK-OPENING STRESSES

8. ITERATIONS EXCEED 100 IN SUBROUTINE FNC
   Crack length cannot be found from input ΔK and Smax.
   Check input data, loading and specimen dimensions.

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13. ABSTRACT *(Maximum 200 words)*

Fastran-II is a life-prediction code based on the crack-closure concept and is used to predict crack length against cycles from a specified initial crack size to failure for many common crack configurations found in structural componments. FASTRAN-II is an update of the previous version FASTRAN. The life-prediction method used in FASTRAN-II is built around an analytical crack-closure model. The model is based on plasticity-induced fatigue-crack closure and is used to calculate the stress level at which the crack tip becomes fully open during cyclic loading. The applied cyclic loads may be constant-amplitude, variable-amplitude or spectrum loading. Several standardized flight-load spectra (TWIST, Mini-TWIST, FASTAFF, and Felix-28) and other load spectra (Space Shuttle and Gaussian) are included as options. Spectrum loads may also be input by the user as either a list of stress points or a flight-by-flight sequence. The program uses the crack-closure concept to account for load-interaction effects. Tensile or compressive loads can be applied. The program contains seventeen predefined crack configurations; and the user can define one crack configuration. The crack-opening stresses, as a function of load history and crack length, are calculated from the model and the effective stress-intensity factor range, used to correlate fatigue-cractk growth rates, may be either elastic or modified for plastic yielding at the crack tip. Ten example problems are included with the user guide to demonstrate the many options in FASTRAN-II.

A computer program DKEFF was also developed to analyze laboratory specimen data to obtain the effective stress-intensity factor agains crack-growth rate relations used by FASTRAN-II. A user guide for this program is also included and discussed. (Computer programs are available from COSMIC.)

14. SUBJECT TERMS

FASTRAN; Fatigue; Cracks; Fracture; Crack propagation; Plasticity; Stress-intensity factor

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